A model for creating simulated medical equipment in a situational gameplay context: The virtual ventilator

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Abstract

Translating the proper use and settings of medical equipment into immersive gameplay that fulfills educational objectives presents multiple design challenges. This paper presents ten parameters for a model to create virtual medical equipment used in nursing education and other fields. Rationale behind virtual medical equipment simulation, as well as justification for the proposed model, based on lessons learned is included. The method for creating the model is explained by a two-part examination of the need for medical equipment simulation and the heuristics of the model itself. The model proposed is part of the design and research of an interactive course, NursingAP.com, a full online curriculum for graduate nursing students seeking a nurse practitioner degree in neonatal healthcare. The data collection methods for quantification of learning objectives through gameplay in the virtual ventilator are also discussed as a mechanism to improve design. Conclusions about the model and future enhancements for validation and investigation are detailed.

Keywords: aviation, computer, equipment, healthcare, mechanical, medical, model, simulation, virtual

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Modeling virtual medical equipment as a component for online nursing education offers many learning experience advantages, particularly when the learning is in a patient situational environment. Yet, few studies focus on the characteristics of virtual medical equipment simulation and how virtual medical equipment may inform positive interventions for immersive gameplay. This paper attempts to redress this gap in the literature by presenting ten parameters for a model of medical equipment simulation design. Information on the challenges and importance of translating parameters and concepts from nursing subject matter experts to simulation designers is discussed. The lessons learned from heuristic design based on education, discovery, and experience are also incorporated.

The NursingAP.com website is a full online curriculum for graduate nursing students seeking a nurse practitioner degree in neonatal healthcare (NNP). The curriculum includes profnotes, -- professor notes and lectures, a variety of complex interactives such as the virtual ventilator and a situational 3D game, the Virtual Neonatal Intensive Care Unit (vNICU) -- featuring 4 patient cases. As such, NursingAP.com is meant to complement face-to-face, online, and blended learning course formats with diverse assets for learning. Figure 1 below is the dashboard for NursingAP.com, and illustrates all the learning assets of the completed project.

Figure 1. The NursinGap.com dashboard incorporates professor notes, complex interactive assets such as the virtual ventilator, and the vNICU game which features four premature infant patient cases.

The virtual ventilator is a key interactive learning asset, ultimately designed to teach NNP students how to write orders for a respiratory therapist. Lessons from the virtual ventilator, along with concepts from other learning assets on the site, culminate in the vNICU, a game-based simulation which incorporates the entire curriculum into a 3D game to utilize critical thinking skills in an immersive environment. Four premature infants in varying degrees of respiratory distress are presented as cases in the vNICU. The positioning of the virtual ventilator within the full NursingAP.com curriculum is presented below.

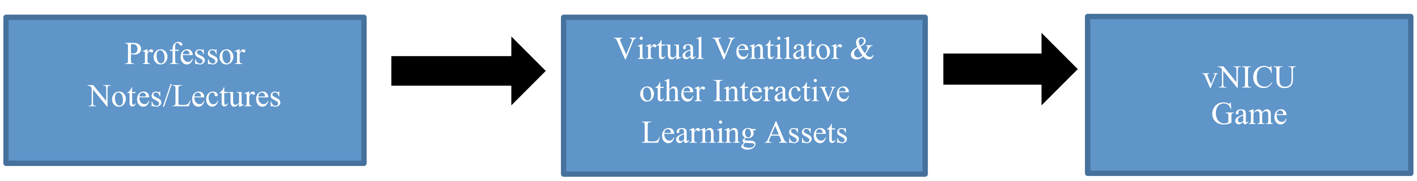

Figure 2. Student educational steps from knowledge to application in NursingAP.com. Professor notes or lectures introduce concepts, which are explored more deeply in interactive learning assets such as the virtual ventilator. All of the learning points come together in the vNICU game, where four virtual infant patients are treated. Students are free to navigate the curriculum in whatever order they wish.

Literature Review –The Role of Virtual Equipment within Simulation

The Need for a Model for Virtual Equipment

Modeling virtual equipment is important in many fields. Industries such as aviation, mechanics, and healthcare, among others, currently use some form of virtual equipment simulation. (Jackson & Batstone, 2008, Ackermann, 2009, Wang & Qui, 2011). The value of a model for medical equipment simulation includes that it allows future researchers to use the knowledge gained from this study in their development, it explains the nature and challenges of simulation design phenomenon, and according to Schreuder, van Dongen, Roeleveld, Schijven, et. al, it creates a quantifiable and noticeable mechanism to create improvements in training (2009). Healthcare and unrelated fields might benefit from such a model.

Rationale for the model

Game-based learning environments provide new options for learners and instructors. Many instructional designers such as professors, medical faculty, and military trainers are interested in incorporating video games and blended learning into curricula. A well-designed, web-based situational learning management system, or SLMS, allows for increased distribution of learning assets and capabilities as well as information architecture agility – using loosely coupled, exchangeable components, while avoiding stovepipe solutions with limited functionality. However, not many platforms deliver blended learning assets in a holistic manner or provide the opportunity to study how the learning assets work together with games. Opportunities exist to study how students respond to different types of interactive media vehicles and which ones are most effective for different learning styles and topics. Studying student response to digital learning vehicles should provide refinement of technologies to enrich teaching, learning and instructional development. The SLMS developed in NursingAP.com lays the foundation for addressing these issues in a game-based environment. While the topic of this particular development is neonatal nurse practitioner training, the SLMS can be used for a variety of curriculum topic sets. However, in many advanced training and educational environments, it is impossible to separate the training of key pieces of equipment from the educational context. For example, virtual simulations of treating a heart attack patient with a defibrillator almost certainly call for the equipment to be not only modeled, but interactive for the student to apply their knowledge of how to treat the patient.

Virtual Simulations – General reasons for use

The same advantages for using virtual simulation overall apply to virtual equipment. These reasons fall into categories such as: cost, learning modalities, increased practice time, safety, personnel requirements, student enjoyment, and quantification of results.

Cost-effectiveness is frequently cited as one of the most important reasons for virtual simulation (Moreno-Ger, Torrente, Bustamante, Fernandez-Galaz, Fernandez-Manjon, et. al, 2010, Çetin, 2012, National Training and Simulation Association, 2012), but it is not the only reason. Virtual simulation is useful for teaching students with various learning styles. According to Graf, Kinshuk, Zhang, Maguire, and Shtern, virtual simulations are especially useful for all the Felder and Silverman Learning Style Models, or FSLM (2012). These modalities include individuals who learn best by actively and reflectively acquiring knowledge, those who are best at using their sensing and intuitive skills toward practical skill pursuits, people who are best at mastering skills through visual and verbal knowledge, and students who grasp material in sequential and global steps by understanding holistically (Felder & Silverman, 1988, 2002). A SLMS approach which allows for learning style differences therefore allows students to learn using their preferred approach.

Virtual simulation also allows students to practice in various locations, convenient to the student's schedule and for an unlimited duration. The richly immersive world of simulation places the student in the context of the setting without the risk of mistakes on live patients or actors, while allowing students the enjoyment of learning. Finally, virtual simulation allows for quantifiable results (Rogers, 2011, National Training and Simulation Association, 2012). These results may then be applied towards creating more effective training and better virtual equipment, leading to a cyclical process for constant assessment and improvement of simulations.

Virtual Equipment – Specific reasons for design

Virtual equipment currently exists in diverse contexts with a wide range of applications. Virtual medical equipment may be found in full virtual worlds with an immersive context such as Second Life (Rogers, 2011), simplistic box trainers that have no immersive context whatsoever (Tanoue, Ieriri, Konishi, Yasunaga, Okazaki, et. al, 2007), flight simulations where students sit in simulated cockpit environments (National Training and Simulation Association, 2012), and even web-based instruction and games (Çetin, 2012). Healthcare is increasingly utilizing virtual simulation. Medical situations provide a wide range of contexts in which an SLMS may inform study on procedures and equipment used in learning.

Multiple types of virtual equipment simulation exist in healthcare settings currently. An experiment designed by Tanoue, Ieriri , Konishi, Yasunaga, Okazaki, et. al. built a virtual set of surgical instruments to teach medical students fundamental skills of endoscopic surgery (2007). A blood sample measured for hematocrit (the volume percentage of red blood cells in blood) was built into the learning module created by Moreno-Ger, Torrente, Bustamante, Fernandez-Galaz, Fernandez-Manjon, et. al to supplement medical school instruction (2010). Chodos, Stroulia, Boechler, King, Kuras, et. al. and the Interdisciplinary Health Education Partnership created diagnostic equipment for interacting with accident victims in a simulation to teach student Emergency Medical Technicians, or EMTs, in Second Life (2010). Zielke, LeFlore, Dufour, Hardee, Huber, et.al. constructed a virtual clinical environment and patients, including heart and respiratory monitors and intravenous therapy solutions for nursing students (2010). The Critical Life Project, explained by Rogers in his study, allows nursing students from Australia to test blood pressure on virtual patients in Second Life (2011). An educational module is used in intensive care units for training of intensive care unit technicians about medical equipment such as defibrillators, electrocardiograms (ECGs), and infusion devices at the Turkish High Specialized Hospital (Çetin, 2012). These are just a few of the examples of virtual medical equipment. However, from these examples, it is apparent that virtual medical equipment is becoming more widely used and accepted as a way to educate healthcare professionals.

While many types of virtual equipment exist, few complex pieces of equipment are fully interactive. For example, the virtual medical clinic created in Second Life which Rogers explains shows various equipment, but only readings and a few small medical appliances such as tubing, stethoscope and needles are used for teaching purposes (2011). This is most likely due to the fact that designing virtual equipment knobs, settings, and the situation in which the equipment is used creates demanding and progressively difficult challenges for design teams.

Nevertheless, the reasons for the creation of virtual equipment are increasingly apparent. First, the ever-increasing costs of equipment, training, and personnel provide the impetus for virtual equipment design. In one web-based healthcare simulation, Moreno-Ger, Torrente, Bustamante, Fernandez-Galaz, Fernandez-Manjon, et. al created a healthcare module providing 30 minutes of instruction for only $7.00 per student (2010). The U.S. Army uses virtual simulation of flight, tank, and other equipment for a savings of $68 million for active forces and $55 million for Army Reserves yearly (National Training and Simulation Association, 2012). Secondly, the user of virtual equipment has a greater ability to master the equipment, since the equipment exists in the virtual world, so it is not in use by others. Third, the user may safely practice on the equipment in a setting which is free of the harsh consequences which might otherwise apply. For example, the use of the virtual ventilator in NursingAP.com to regulate blood gas within a neonatal infant is an interactive asset to help the nursing student acquire the skills to learn how to give orders to save the infant's life. The situation is virtual, not real, allowing the nurse to make mistakes which in a live hospital setting could potentially harm or kill the child. Through the use of virtual equipment, however, the nurse obtains the knowledge and practice to recognize what should be done in this context without the fear of jeopardizing the life of the infant (NursingAP.com, 2012).

The future of medical training includes virtual equipment

The need for training using virtual equipment will continue to be important for the foreseeable future due to several factors. Within the healthcare context, this is because the shortage of medical faculty to educate other medical professionals is acute. Due to physician and nursing faculty retiring, working a shorter number of hours, or physician and nurse migration to other countries, fewer medical faculty are available for training (AMA, 2012). The U.S. (AMA, 2012) India, (ZeeNews.com, 2011) Pakistan, Canada, (MacLaughlin & Walker, 2010), as well as many African countries (Mann, 2011) are experiencing a shortage of medical faculty and trained medical professionals. The U.S., due to the passage of President Obama's Patient Protection and Affordable Care Act, could potentially place even more of a strain on the healthcare system's need for trained professionals as more Americans gain access to healthcare than ever before (http://www.hhs.gov/, 2012). With the shortfall of trained medical faculty so apparent, some mechanism to train medical professionals on equipment must be found to alleviate this burden. Simulation of medical equipment means that fewer faculty need to supervise over the training, while maintaining a high standard of learning. Additionally, the training may be standardized. This benefit allows for medical professionals across areas to understand and communicate how the equipment is used to patients and caretakers in a way which until recently was impossible.

As healthcare professionals face the challenges inherent to learning new equipment, the motivation to learn is an advantage of simulation which cannot be understated. Medical professionals face long hours of theoretical and practicum coursework in their training. Their training continues even after graduation with certification courses and additional instruction. The need to train on new medical equipment is also constant as new technical advances lead to newer medical equipment and procedures. Because simulation training of equipment is highly motivating, according to Mantovani, Castelnuovo, Gaggioli, and Riva (2003), it provides an outlet for students and trained healthcare professionals to play the simulation and learn new equipment. The incentive to learn through enjoyable play is not only understandable, but a desirable consequence. Virtual medical equipment training is both student-centered and focuses on learning by actively adjusting the equipment to experience the consequences of use and misuse of equipment, thereby promoting learning and instilling positive attitudes toward learning and a deeper understanding for students (Michael, 2006).

According to several studies, interactive equipment simulations are effective at teaching medical procedures. For example, Tanoue, Ieriri, Konishi, Yasunaga, et al., found that surgical skills were enhanced by using simulated scalpels during endoscopic surgery over both a black box simulation group and control group (2007). The 2012 study done by Çetin showed how

EMTs trained on virtual medical equipment were both satisfied with their training and received higher scores than those who did not train on the virtual equipment. Zielke, LeFlore, Dufour, Hardee, Huber, et. al., suggests that simulation creates a positive environment whereby those who play the simulation may immerse themselves in the simulation while learning valuable skills that translate outside of the virtual environment and into the greater world outside (2010). Due to the rapidly changing technological equipment in the medical field, it is not an option whether or not to train using computers, but rather a dilemma as to how best to educate professionals in an effective and practical manner. Ericsson, Krampe, and Tesch-Romer point out that it takes 10,000 hours for an individual to attain mastery of a subject (1993). Virtual experiences with medical equipment provide a low-cost, safe manner in which many of those hours may be obtained to master the use of life-saving equipment. When all of the reasons for virtual equipment simulation are aggregated, ten parameters for a model of virtual equipment design become apparent. These are discussed later in the paper.

Methods

The creation of ten parameters for a model of medical equipment simulation comprises two main parts. The first involves the heuristics surrounding the model. The second is the ten parameters of the model itself. The model comprises the ten points that take a project from translation to conclusion of the project.

Heuristics of the model creation

How a team of simulation designers and subject matter experts collaborate to bring abstract concepts to finalized virtual experiences is an increasingly important consideration. As professionals specialize into more narrow fields of study, it becomes difficult to find those who bridge diverse skill sets to facilitate collaboration. While subject matter experts have a deep understanding of the situation, equipment, and patients in which the simulated equipment should exist, they may not understand how to translate this into a virtual, immersive experience. On the other hand, game and web developers likely will not have deep medical knowledge. For example, in the case of the virtual ventilator, simulation developers did not possess the deep medical expertise of the four person nursing faculty team subject matter experts. For their part, the nursing faculty had never attempted to create a web-based curriculum with multiple interactive assets, and a vNICU game. The combined design team of subject matter experts and developers is where the value of the project truly forms as both find approaches to solve challenges. The process by which the ventilator on NursingAP.com was created exemplifies this situation.

Clarity of the purpose of the virtual ventilator in this particular curriculum also had to be established. During the talks with the nursing faculty, the prime objective surrounding the teaching of the ventilator equipment was that the nursing students needed to learn how to give orders to change the settings, but the game needed to communicate that an incorrect decision could lead to the death of a child. These sorts of medical decisions are part of the everyday life of healthcare providers, but not part of the fidelity of most games. The virtual ventilator needed to establish empathy and ethical sensitivity towards the scenarios designed for gameplay – also a design construct often not present in entertainment games. To this end, students were encouraged to work with choices throughout the ventilator, and given feedback to go back and change their answer if an incorrect choice was made. This also simplified development, in that the students were not given an opportunity to twirl the dials in an open-ended manner.

Ten point virtual medical equipment simulation model for design translation

Given the experiences on the NursingAP.com project a ten-point virtual medical equipment simulation model has been derived which summarizes the lessons learned on the development. The ten model components are elicited below and will be discussed throughout the remaining paper.

1. Agent integration: Value of an agent in educational strategies.
2. Choices: What is put into the simulation and why? Which scenarios to include.
3. Data: How and what information is collected and for what purpose?
4. Engagement: Making the player engaged.
5. Feedback: How and why is it given, what challenges need feedback.
6. Motivation: Strategies for increasing or decreasing player motivation; using a game construct; decisions on positive or negative feedback.
7. Fidelity: How real is the simulation? How expansive is the player experience?
8. Sounds: Ambient, tension, feedback, and equipment sounds.
9. Translation: Degree of parallel to "real life."
10. Visualization: What does the equipment look like? What room is it in? Who uses it? Where does it appear in the simulation?

    These ten points, and lessons learned on each component, will be discussed throughout the remainder of the paper.

Results

Early design stage decisions: Fit with curriculum, affordances and other important design decisions

Fit with curriculum

The subject matter experts for NursingAP.com spent many hours deciding on the full online NNP curriculum. Within this context, the virtual ventilator was chosen as a key tool for teaching the students how to care for infants in varying degrees of respiratory distress – a condition often found in the real-life NICU. Many questions such as what the ventilator should look like, which actual ventilator model to represent, what settings to include, how to best represent changes in the ventilator readings, what sounds to include and how to represent actual effects on a patient became important design decisions. The primary learning objective of the virtual ventilator interactive was to inform orders that would eventually be written in the vNICU game. These primary learning objectives also included interpreting objective physiological data such as chest x-rays and arterial blood gas levels to teach students how to diagnose an infant with respiratory distress.

Affordances

Affordances, as stated by Zielke, LeFlore, Dufour, Hardee, Huber, et. al, are behavioral impressions gathered by an individual from the speed and direction of a pattern, as well as the orientation and frequency with which the pattern exists in static objects and places in the virtual environment (2010). Elements in a simulation therefore communicate information to individuals based on the perception of the individual user. The intention of the individual in using the virtual ventilator and what it represents to the individual may therefore be received completely differently from student to student. Such aspects as color, movement speed, and culture may affect how equipment is perceived. The virtual ventilator may represent a life-saving device to one student, another may see it as an obstacle to be overcome to achieve knowledge in the class, still another might view the ventilator as a cold, unfamiliar machine to be feared. The simulation designers needed to keep affordances in mind, while representing the equipment within the context of the learning environment successfully.

Other important design decisions: the fidelity and open-endedness of the virtual ventilator

Other important design decisions had to be made at the starting point of the virtual ventilator as well. One key and complex decision was the level of fidelity of the virtual equipment. Since 5 knobs with many different combinations appear on most ventilators, it would be impossible to account for every variation to give feedback for all the possible blood gas levels infants might have. This led to the creation of some limits for settings to give proper feedback to the NNP students. Additionally, since various brands of ventilators exist, a single one was not chosen as the model. In other words, the virtual ventilator incorporates the concept of a real machine, but not a replication of one particular model. Further, the in-hospital role of an NNP was also modified in the simulation. In the simulation, the nursing students change knobs on the ventilator, but in practice, this task is performed by a respiratory therapist, through an order written by an NNP. To this end, the ventilator was designed to enhance complex analytical thinking skills, rather than a strictly realistic work experience. Figure 3 below is a screen shot of the ventilator representation and the virtual patient designed as part of the complex interactive to show the oxygen flow in and out of the patient's lungs.

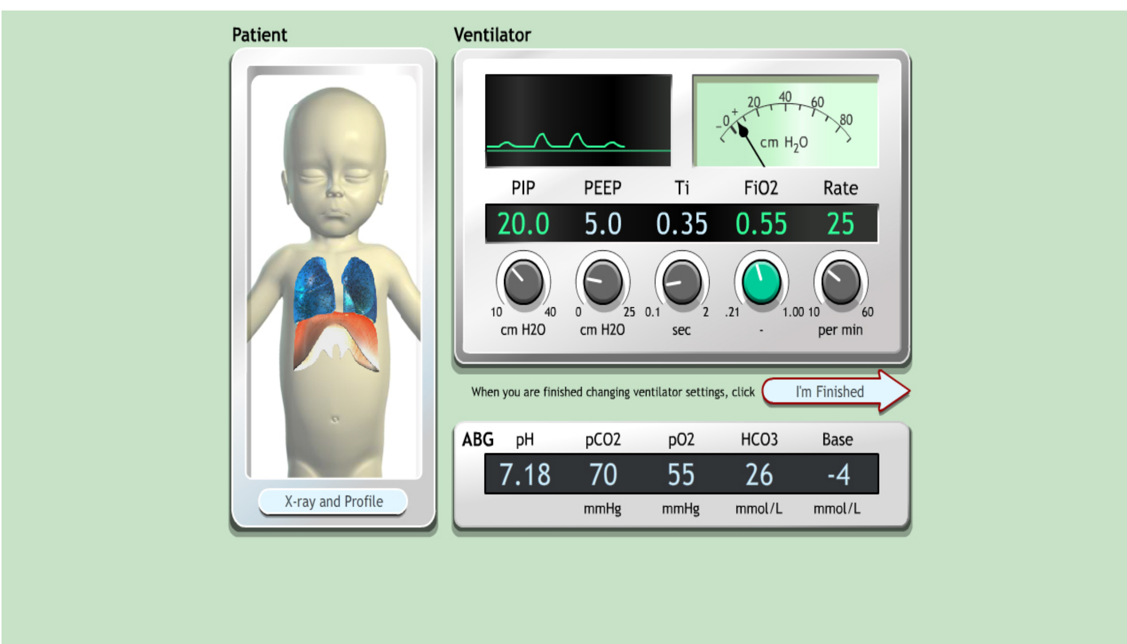

Figure 3. The virtual ventilator with 5 knobs is a representation of a ventilator and not a one-to-one representation of any particular model.

Mid-design stage of the virtual ventilator – Adding an Agent and Decisions on Data Collection

Conceptually, the virtual ventilator needs to contain not only the educational elements important for knowing how to operate the equipment, but also interactive elements to keep students engaged in the learning process. This was how “Pop-up Judy,” the nursing professor agent, entered the design process. “Pop-up Judy” is a virtual agent which looks like Judy LeFlore, Ph.D, the professor for the course. This virtual agent gives friendly advice and positive feedback to students within the vNICU game. The inclusion of a virtual agent was chosen to make the interactive more personal to the students as well as to provide a function for feedback. Clark and Mayer suggest that a pedagogical agent can act to aid the learning process (2003).

Based on previous work with physical manikins in healthcare research, a positive feedback strategy was selected. As indicated in figure 4 below, this approach led to the design of Pop-up Judy saying, “Excellent!” when a student correctly ordered an optimal blood gas level in the game by using knowledge from professor notes and lecture. This provided a reward learning mechanism, rather than a punitive approach, facilitating a positive situational earning experience, rather than a negative one, for gaining the applied knowledge available through the virtual ventilator.

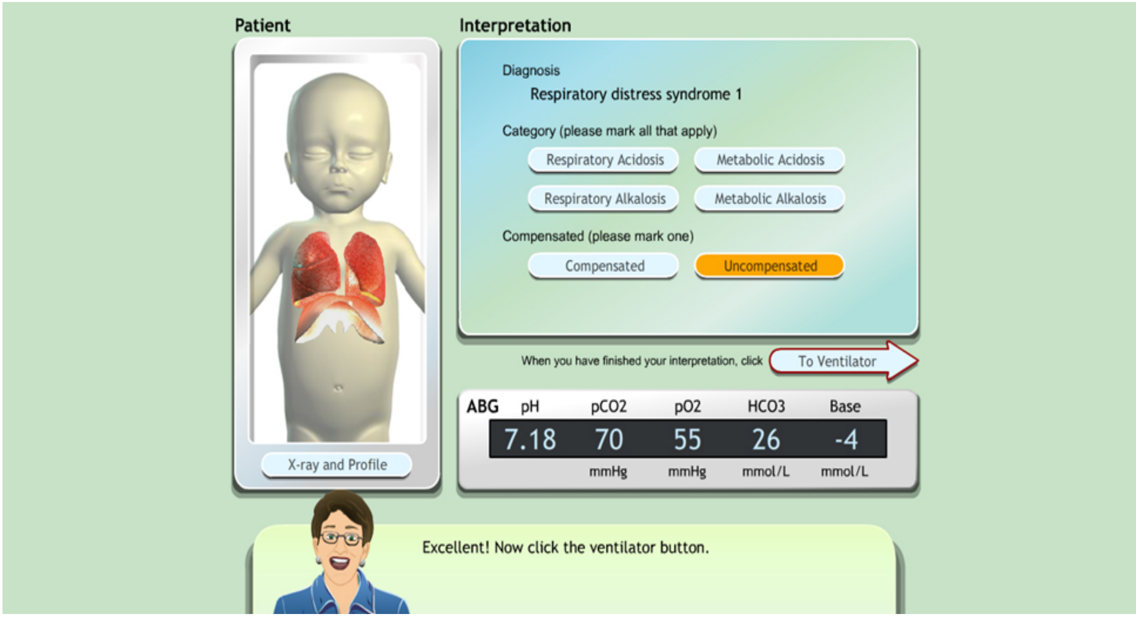

Figure 4. Pop-up Judy gives positive feedback in the ventilator interactive, praising students when correct decisions are made and using positive redirection when the student must change initial answers.

Data collection is another important design decision made at this stage. A clear benefit of web-based systems is the ease of raw data collection. NNP students represent a rich, diverse set of individuals. Through background collection of demographic and click-stream data, trends and group differences can be observed and quantified. The purpose of evaluating this data is to tease apart the impact of various demographic and group characteristics on learning through processes such as the virtual ventilator. Further, understanding how users navigate through the virtual ventilator content and how many times users engage in the ventilator in the context of other learning assets, are also important topics for analysis.

The expected interaction model for a user motivates data gathered from the interactive ventilator. Every time a user begins using the ventilator they must first select a case. Subsequently, they select one of the 4 categories of disorders, followed by compensated or uncompensated based on medical history for the virtual patient. They must make these choices repeatedly until both are correct in order to be allowed to progress to the ventilator. Subsequently the user adjusts the ventilator knobs in order to treat the patient.

As this is a learning exercise the data primarily of interest is user error per case. As such, all tracking is done at the level of individual case studies even though the user may select multiple cases during a single session with the ventilator. Thus, per user and per session we track a set of random variables indicating errors. For the first screen where the user selects disorder categories we track 6 Boolean variables indicating whether or not each button was clicked in error. This is predicated on the assumption that a user will not intentionally select a wrong value more than once. The correct buttons for a given case will never have a value of true, but this representation is maintained for consistency across all cases.

Subsequently, the user must adjust a number of knobs to treat the patient. Again, we are interested in errors. This is problematic as the user may set a value too low, too high, or correctly. It is important to note that each ventilator has 3 snap points to which the knob will jump if it is released. The chosen snap point is the closest one. There is a snap point above, below, and at the correct value. Since the user is not allowed to progress until they correctly adjust all knobs we track 2 scalar variables for each knob. These are an overcorrect delta (indicating how far above the correct value the user set the knob) and an under-correct delta (indicating how far below the correct value the user set the knob). It is possible for both variables to be non-zero in a single run. Together all of these variables capture all cases of potential user error.

Final stages of the virtual ventilator: Using the virtual ventilator concepts in the vNICU

As stated earlier, ultimately the purpose of the virtual ventilator is to facilitate writing correct orders in real NICU patient situations. To this end, the final manifestation of the virtual ventilator lessons is in the vNICU game that is part of the overall NursingAP.com curriculum. As outlined earlier, the vNICU is a game available to students where four patient cases require NNP students to physically assess patients, order and review labs, and write orders based on their assessments, to include those on ventilator settings. The four patients that are part of the vNICU game, are illustrated below in figure 5.

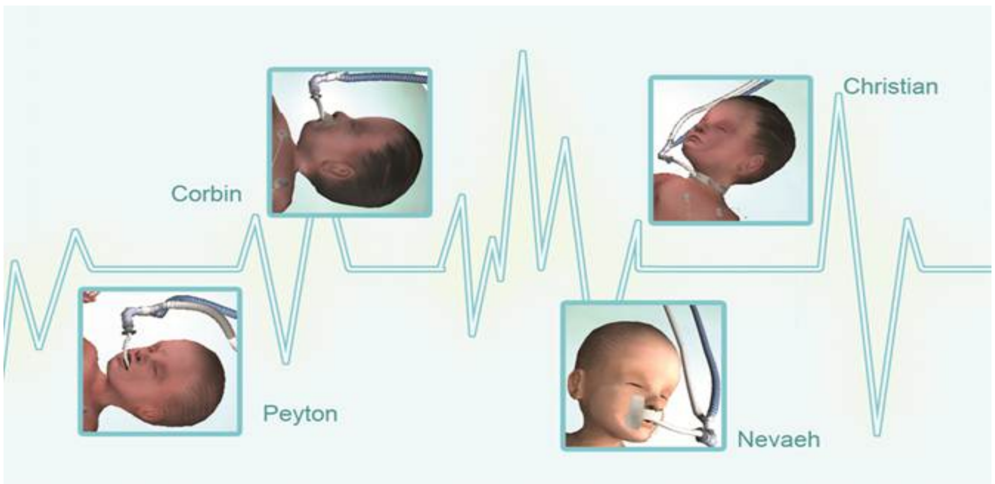

Figure 5. Four premature infant patients are presented in the vNICU. Each of these patient cases require that the student NNPs examine the patient, order and review labs, and write orders, to include those on the virtual ventilator.

Another representation decision that needed to be made within the game was how to represent the actual writing of the ventilator orders. Again, because of an infinite number of possible permutations, parameters had to be set, within the guidelines of reasonable professional decisions that limit the order choices possible to increase, decrease or not change current ventilator settings around a limited number of options. This is illustrated in figure 6 below.

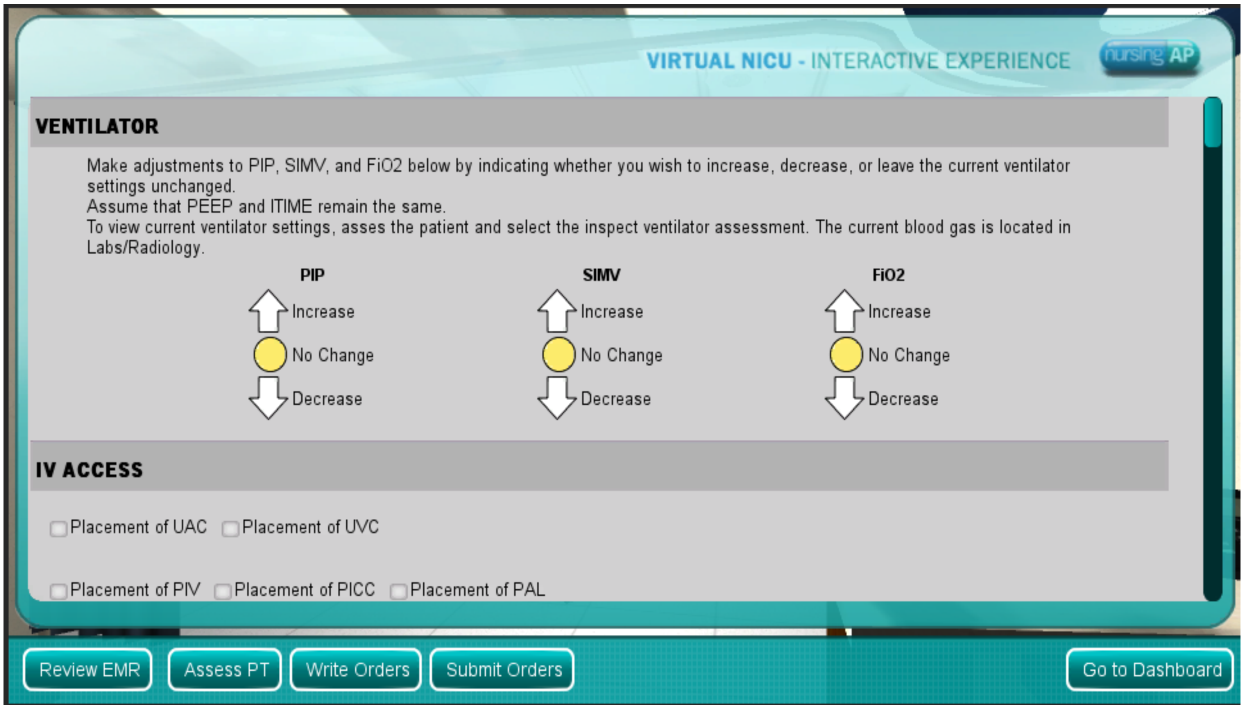

Figure 6. Instructions regarding ventilator settings are among the order decisions student NNPSs make in the vNICU game. Possible decisions are limited to increase, decrease or leave unchanged current settings around a limited number of options within reasonable professional guidelines.

Discussion

Many important lessons from the virtual ventilator project derive from the design process. These lessons are from areas as diverse as fidelity to quantifiable data gathering methods. Understanding the limitations of the software, budget and time involved in a project is one of the largest lessons for not only the design team, but for the subject matter experts. For example, one original concept was to allow the students to adjust the ventilator settings however they wished. This proved impossible because of budget and software limitations as well as desired learning outcomes.

Secondly, data gathering on how students learn the equipment and utilize an educational website must be constructed into the design early on and with clear mechanisms for analysis. If data gathering strategies are not included into the coding of the learning module at the beginning of the design process, it is far more expensive and time-consuming to do after project completion.

The third important lesson involves student feedback. Eventually the nurses “won” the ventilator lesson by adjusting the knobs on the ventilator to produce an optimal blood gas over and over again. The addition of only positive rewards, rather than punitive feedback, placed a higher emphasis on critical thinking skills and the treatment of the infants, which is not an intuitive design element for many designers used to making entertainment games. Positive feedback allows the students to play with the game and learn by doing, rather than causing frustration with the game. This implies that designers for virtual simulations must learn new feedback approaches which differ from entertainment games. Research would be helpful in this area, however to determine if it is more desirable to allow students to actively change the knobs or adjust the equipment in a more open-ended manner.

The last lesson learned dealt was initial positive feedback to the agent, Pop-up Judy, modeled after the lead professor for the NursingAP.com project. The initial reaction the students had was positive, suggesting that personalization of educational game and website design makes for a more enjoyable experience for students.

While many positive lessons were learned from this project, several areas for research remain. As more software becomes available at lower cost for web browser games, phone games, and similar platforms, more detailed and higher fidelity models will become easier to include for equipment simulations such as the virtual ventilator. Since the virtual ventilator was created to complement online, face-to-face, and blended learning, questions of how best to make virtual equipment to educate students, what sort of self-exploration students perform on the equipment, and the best ways to integrate the stand alone interactive assets and games into educational contexts will need to be explored. Finally, what components the students desire to have included in virtual equipment and their perception of virtual equipment are obvious areas for further research.

Virtual equipment is increasingly used in industries as diverse as aviation, education, healthcare, and mechanical engineering. This use will proliferate in the future due to the benefits of simulation and virtual equipment training. The major challenges facing designers of virtual equipment, though, will remain the same. Through collaboration, subject matter experts and simulation designers can translate concepts into contextually rich, immersive game-based simulations to train students on technology. The ten parameter model of virtual equipment presented here suggests design points to begin this translation process, and has application across a variety of industries.

Note for disclosure: Dr. LeFlore previously presented the virtual ventilator at a conference on the nursing educational benefits of NursingAP.com. Dr. Zielke has presented an overview of NursingAP.com at Gametech 2012. Neither presentation was on the design strategies and challenges of virtual medical equipment, which is the focus of this paper.

References

Ackermann, A.D. (2009). Investigation of learning outcomes for the acquisition and retention of CPR knowledge and skills learned with the use of high-fidelity simulation. *Clinical Simulation in Nursing, 5*(6). doi: 110.1016/j.ecns.2009.05.002

American Medical Association. (2012, March 28) "Do We Need More Physicians or Efficient Health Care?" *AMA webpage*. Accessed on March 28, 2012 from http://www.ama-assn.org/ama/pub/education-careers/graduate-medical-education/question-of-month/need-more-physicians.page

Çetin, A. (2012). 3D Web based learning of medical equipments employed in Intensive Care Units. *Journal of Medical Systems, 36*. 167–174 doi:10.1007/s10916-010-9456-5

Chodos, D., Stroulia, E., Boechler, P., King, S., Kuras, P, Carbonaro, M., & de Jong, E. (2010). Healthcare Education with Virtual-World Simulations. *SEHC '10 Proceedings of the 2010 ICSE Workshop on Software Engineering in Health Care. ACM*. Accessed on March 27, 2012 from http://delivery.acm.org/10.1145/1810000/1809097/p89-chodos.pdf?ip=129.110.241.140&acc=ACTIVE%20SERVICE&CFID=74371425&CFTOKEN=52577219&__acm__=1332881678_d0e085594c53491e254fffb2ff51f6f0

Clark, R.C., & Mayer, R.E. (2003). *E-learning and the Science of Instruction*. San Francisco, CA: John Wiley & Sons, Inc.

Ericsson, K.A., Krampe, R.T., & Tesch-Romer, C. (1993). The Role of Deliberate Practice in the Acquisition of Expert Performance. *Psychological Review,100*(3). 363-406.

Felder, R. M., & Silverman, L. K. (1988). Learning and teaching styles in engineering education. *Engineering Education, 78*(7). Prefaced by Felder in 2002 on changes made since 1988.

Graf, S., Kinshuk, Zhang, Q., Maguire, P., & Shtern, V. (2012). Facilitating learning through dynamic student modeling of learning styles. In *Towards Learning and Instruction in Web 3.0: Advances in Cognitive and Educational Psychology*. P. Isaias, D. Ifenthaler, Kinshuk, D.G. Sampson, J.M. Spector (Eds.). New York, NY: Springer

Jackson, H. & Batstone, G. (2008). Case study: Closing the gap with 3D interactive simulations. *Spring Simulation Multiconference 2008*. Accessed on June 6, 2012 from http://dl.acm.org/citation.cfm?doid=1400549.1400660

MacLaughlin, R. & Walker, L.C. (2010). "International Summit Seeks Solutions to Global Shortage of Nursing Faculty." *Sigma Theta Tau International Honor Society of Nursing website*. Accessed on March 28, 2012 from http://www.nursingsociety.org/Media/Pages/summit_seeks_solutions.aspx

Mann, S. (2011, April). "PEPFAR Program to Improve Africa's Health Care, Medical Education." *Association of American Medical Colleges website*. Accessed on March 28, 2012 from https://www.aamc.org/newsroom/reporter/april11/184294/pepfar.html

Mantovani, F., Castelnuovo, G., Gaggioli, A., & Riva, G. (2003). Virtual fidelity training for health-care professionals. *Cyberpsychology & Behavior, 6*(4). Accessed on March 26, 2012 from http://www.cybertherapy.info/VR_training_in_health_care.pdf

Michael, J. (2006). Where's the evidence that active learning works? *Advanced Physiological Education, 30*(4): 159-67. doi:10.1152/advan.00053.2006

Moreno-Ger, P., Torrente, J., Bustamante, J., Fernandez-Galaz, C., Fernandez-Manjon, B., & Comas-Rengifo, M.D. (2010). Application of a low-cost web-based simulation to improve students' practical skills in medical education. *International Journal of Medical Informatics, 79*. doi: 10.1016/j.ijmedinf.2010.01.017

National Training and Simulation Association. (2012). "Why Use Simulation? - Return on

Investment." Accessed on July 7, 2012 from http://www.trainingsystems.org/publications/simulation/roi_effici.cfm

NursingAP.com. (2012). Developed by University of Texas at Dallas, Arts & Technology Program. www.nursingap.com.

Patient Protection and Affordable Care Act. (2012). Accessed on July 10, 2012 from U.S. Department of Health and Human Services website at http://www.hhs.gov/

Rogers, L. (2011). Developing simulations in multi-user virtual environments to enhance healthcare education. *British Journal of Educational Technology, 42*(4), 608–615. doi/10.1111/j.1467-8535.2010.01057.x/pdf

Schreuder, H.W., van Dongen, K.W., Roeleveld, S.J., Schijven, M.P., & Broeders, I.A. (2009). Face and construct validity of virtual fidelity simulation of laparoscopic gynecologic surgery. *American Journal of Obstetric Gynecology*, 200(5). 540.e1-e8 doi: 200:540.e1-540.e8

Tanoue, K., Ieriri S., Konishi, K., Yasunaga, T., Okazaki, K., Yamaguchi, S., Yoshida, D., Kakeji, Y., and Hashizume, M. (2007). Effectiveness of endoscopic surgery training for medical students using a virtual fidelity simulator versus a box trainer: a randomized controlled trial. *Surgical Endoscopy*. Accessed on March 25, 2012 from http://www.springerlink.com/content/l12413656g473876/fulltext.pdf

Wang, H., Qui, Y-F. (2011). Virtual aircraft instruments based on VAPS. *Computer Systems and Applications, 20*(11).

ZeeNews.com. (2011, January 20). "Centre taking measures to tackle shortage of medical faculty." *ZeeNews.com website*. Accessed on March 28, 2012 from http://zeenews.india.com/news/nation/centre-taking-measures-to-tackle-shortage-of-medical-faculty_681973.html

Zielke, M., LeFlore, J., Dufour, F., Hardee, G., Huber, M., Thomas, P., Kanipe, K., Whetstone, E., & Buxcamper, A. (2010). Game-Based Virtual Patients – Educational Opportunities and Design Challenges. *Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2010*. http://utdallas.academia.edu/frankdufour/Papers/985631/Game-Based_Virtual_Patients-Educational_Opportunities_and_Design_Challenges