Virtual Simulation and Serious Games for Medical Education: A Review of the Literature and Development of a Virtual Peritoneal Dialysis Simulator

Citation

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Abstract

Background: Novel training modalities are needed for medical education, specifically to teach difficult and globally applicable skills such as peritoneal dialysis (PD). E-learning strategies, including serious games, have demonstrated effectiveness in teaching, including within nephrology. Here, we summarize the literature describing serious gaming in medical education and describe the development and release of a virtual PD simulator.

Methods: The simulator was developed in an iterative process that included formative evaluation. Thirteen subjects underwent Think Aloud Protocol testing and Likert scale system usability scale (SUS) surveys in four cycles. The simulator was released on OPENPediatrics (www.openpediatrics.org), a free medical education website, on January 28, 2016, with usage tracked through March 2016.

Results: A PD simulator incorporating best practices in game development and adult learning theory was developed. Feedback indicated high usability, utility, interest in future use, and enjoyment. Since its release, 223 users from 51 countries accessed the simulator. Users spent an average of 60 minutes on each of three sections. Completion rates for each section range from 41% to 61%. 47%-69% of users scrolled through the text, indicating engagement. For a small number of users (n=14), comparing pre- versus post- case-based multiple choice test scores showed an increase of 20 points on post-test scores (p=0.0015).

Conclusions: Through an iterative process and structured formative evaluation, we developed the virtual PD simulator. The process may be generalizable to future serious gaming development in the medical field. In testing, feedback was positive, indicating high utility and interest in use. Since its release, the simulator shows high time-on-task, engagement, and completion rates, as well as potential knowledge gains. The simulator has the potential to teach PD in an engaging, relevant and efficient manner worldwide. Future studies will assess its impact on knowledge gains and influence on practice.
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I. Glossary of abbreviations
ASN = American Society of Nephrology
C = Control
CBS = case-based simulation
ESRD = end-stage renal disease
MCQ = multiple choice questions
PD = peritoneal dialysis
PDSA = plan-do-study-act
RCT = randomized controlled trial
s = seconds
SG = serious game
SME = subject matter expert
SUS = System Usability Scale
VE = virtual environment
VP = virtual patients
VPDS = virtual peritoneal dialysis simulator
II. Introduction and Background

Emerging pressures from a new generation of technologically literate medical learners are urging medical educators to develop and study new teaching strategies for the 21st Century.¹,² The medical community has responded with an explosion of new Internet-based technologies and digital teaching tools that are being utilized across a variety of disciplines and for varied purposes in medicine.²,³ These tools differ in their efficacy and ability to attract the adult learner.²,³ Serious gaming is an appealing new tool because it actively engages the adult learner, allows control of learning pace and timing, provides directed feedback, and leverages cognitive motivations inherent in games.

Serious games are games developed for a purpose other than entertainment, such as teaching a specific knowledge or skill, and are designed to keep players engaged as they “educate, train or change behavior.”⁴ Serious gaming has been used successfully for training in many fields, including business, the airline industry, the military,² and elementary and high-school education, business management, conflict resolution,⁵,⁶ intercultural communication, second language acquisition, science and technology,⁷-¹⁰ to teach critical thinking skills,² and to improve leadership capabilities in real companies.¹¹ In 2012, digital games were reported as one of the six greatest trends in higher education.¹²

The objectives of this report are to summarize the literature describing serious gaming in medical education and describe the development, testing, and results of an original serious game, the virtual peritoneal dialysis simulator (VPDS). We evaluate and classify the current studies on serious gaming using a standard framework. Next, we outline the development of the VPDS, offering a generalizable framework for serious game development. Lastly, we report our formative qualitative evaluation process for the VPDS, as well as the initial results from the pilot release on a free medical education platform, OPENPediatriX (openpediatrics.org).

III. Key Concepts in Serious Gaming
Today’s generation of learners, the “Millennials,” are students born after 1980 whom have grown up immersed in technology, and thus, are technology literate.\textsuperscript{1,13} Because of their immediate access to information on any topic, Millennials are curious, motivated to learn independently, and accustomed to immediate gratification.\textsuperscript{1,13} At the same time, because of their access to a potentially overwhelming amount of information, they seek direction and structure in their learning.\textsuperscript{1} Millennials may be more anxious in new learning situations, but are receptive to feedback and more likely to actively seek feedback than prior generations.\textsuperscript{1,14} Additionally, they are interested in fairness and transparency, seeking unbiased learning environments.\textsuperscript{1} They value aesthetically appealing, fun, game-like, interactive educational materials.\textsuperscript{1,14} Thus, serious gaming is a well-suited educational modality for the learning traits associated with Millennials.

Data supports that Millennials want this form of technology in medical education, and would use serious games on their own time to achieve learning goals.\textsuperscript{15}

There are several broad types of serious games designed for medical education as depicted in Figure 1. A. \textbf{Virtual environments} offer an immersive experience, where users either control an avatar or engage with the virtual environment firsthand.\textsuperscript{16} B. \textbf{Multi-player serious games} allow for collaboration with other users, often using microphones and headsets for voice communication between participants, and can be specifically helpful when teaching concepts such as teamwork.\textsuperscript{16} C. \textbf{Case-based simulations} ground learning in a patient case while incorporating augmented multimedia teaching tools and tests, and these vary greatly in their structure and interactivity.\textsuperscript{17} D. \textbf{Technical trainers} allow users to control virtual tools or devices in order to improve technical skills, often incorporating haptics or touch technology, to simulate the intended content.\textsuperscript{18}
Figure 1. This figure provides examples of different types of serious games used in medical education. A. Virtual environments allow users to control an avatar or engage with the virtual environment firsthand.¹⁶ (Image courtesy of Innovation in Learning, Inc., http://www.innovationinlearning.com/). B. Multi-player serious games allow for voice communication between participants through microphones and headsets.¹⁶ C. Case-based simulations combine patient cases with augmented multimedia teaching tools.¹⁷ (Image courtesy of Learn Physiology: Electrolyte and Acid Base Workshop, http://www.learnphysiology.org/sim1/). D. Technical trainers teach the use of tools or devices and can incorporate haptics or touch technology. (Image courtesy of Chan et al).¹⁸

Serious gaming has many elements that are supported by adult learning theory principles – individualized, self-paced learning that appreciates previous knowledge, is contextualized, and gives users the opportunity for active experimentation.¹⁹,²⁰ Serious games motivate time-on-task, push learners to develop expertise through discrete levels, promote curiosity and interest through competition, and keep learners actively engaged in decision-making that mimics real-life patient care.²¹,²²,²³ Moreover, the
novelty and attractive interface result in a memorable learning experience that targets the education of Millennial learners.¹

Serious games address many of the shortcomings of the present medical education system, and they offer advantages from the perspectives of the learner, educator and developer (Figure 2). They create an opportunity to simulate and practice high-risk and low-volume events, not only allowing practice of critical skills safely, but also providing a more standardized educational experience that removes some of the randomness of experience in the current apprenticeship model of clinical training.²⁴ Additionally, serious games reduce cognitive load for users, which is of particular importance as the body of medical knowledge is expanding exponentially. Serious games break down learning into discrete tasks and reduce demands on working memory by keeping track of user’s resources and prior accomplishments. Furthermore, they allow for reality to be augmented; text, video and animations can be interspersed to reinforce and explain concepts.

<table>
<thead>
<tr>
<th>For the learner</th>
<th>For the educator</th>
<th>For the developer</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Fun and engaging interface, familiar to Millennials</td>
<td>• Augmentation of reality</td>
<td>• Scalable</td>
</tr>
<tr>
<td>• Accessible when convenient and useful</td>
<td>• Manipulation of time</td>
<td>• Ease of distribution</td>
</tr>
<tr>
<td>• Self-paced, learner controlled</td>
<td>• Standardization of content and assessment</td>
<td>• Reusability of materials</td>
</tr>
<tr>
<td>• Immediate feedback</td>
<td>• Enhanced learner time-on-task</td>
<td>• Mobile delivery</td>
</tr>
<tr>
<td>• Capacity for repetition</td>
<td>• Decreased demand on educator</td>
<td></td>
</tr>
<tr>
<td>• Possible anonymity</td>
<td>• Potential cost-savings</td>
<td></td>
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<tr>
<td>• Stepwise learning through tasks and levels</td>
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**Figure 2:** The advantages of serious game-based learning over live instructional modalities, from the perspective of the learner, the educator, and the developer.
As described by Morris et al., the use of gamification in science education supports three key scaffolds of education: motivational, cognitive and metacognitive. Serious games offer motivational scaffolds through feedback, rewards, and the potential triggering of a flow state.\textsuperscript{23} Flow is an optimal state of intense focus on an activity, and video games have been described as “flow machines,” based on their inherent qualities that promote the flow state,\textsuperscript{25,26} and thus behavioral persistence and time-on-task.\textsuperscript{24,27} Cognitive scaffolds are achieved by creating simulations that mimic the clinical environment, are of adequate fidelity to allow transfer of knowledge into practice, and embed important clinical reasoning skills into the serious game. Metacognitive scaffolds promote clinical contextualization of abstract concepts and skills, and provide feedback that promotes reflection.\textsuperscript{23}

A major advantage of serious games is that feedback can be provided in ways that are most effective – goal-centered, sufficient, specific, and given close in time to the event being evaluated.\textsuperscript{23,28,29} While failure and error often result in anxiety and reduced motivation, in games, error and failure do not have this negative impact, and are viewed rather as feedback, which may promote intrinsic motivation.\textsuperscript{25,30}

**IV. Limitations of Serious Games**

Serious games have some technical and conceptual challenges. The biggest deterrents to the development and use of serious games as educational tools are the cost, time commitment, creativity, and expertise in psychiatry and technology required for development.\textsuperscript{31-43} However, if serious games are shared between hospitals and medical schools, the relative cost becomes low, while the convenience, safety and potential for more personalized education is extremely high.\textsuperscript{44} Delasobera *et al.* showed that serious gaming was relatively easy and cheap to implement in a resource-limited environment compared to live simulation, offering a potential cost-saving benefit in this type of educational setting.\textsuperscript{44}

Fidelity refers to the degree of similarity between the game experience and the real...
environment,\textsuperscript{31} and transfer is the process of applying the knowledge gained within the intended real environment.\textsuperscript{32} Because increasing fidelity is associated with increased cost and technical difficulty, it is important to determine how much fidelity is needed to maximize transfer.\textsuperscript{33} A higher degree of fidelity may be needed for training of personnel at later stages of learning.\textsuperscript{31,34} The fidelity-transfer relationship remains poorly defined for serious games in medicine, especially in relation to cognitive skill training.\textsuperscript{33-35}

Games provide extrinsic motivation for behavioral change; thus a potential danger of serious games is the destruction of intrinsic motivators. Studies show that some users report conflict between intrinsic motivation inherent in adult learners and the extrinsic motivation provided by serious gaming.\textsuperscript{42,45} Nosek \textit{et al.} noted the following statement by a user, “My aim became to achieve the learning objectives and get the 100%. I didn’t really try to synthesize the information given to me.”\textsuperscript{46} Thus, care must be taken to develop games that promote intrinsic motivation for learning.

Furthermore, serious games are engaging, but may not be time-efficient. Learners, especially those with limited gaming exposure, need time to familiarize themselves with the game elements and rules before they can begin learning. Additionally, many aspects of medical practice cannot be easily simulated such as certain components of team-based interaction, tactile experiences, and individualized approached to patient care.\textsuperscript{2,39} Lastly, educational goals vary across providers and institutions, so it may be challenging to create games that teach and assess skills and practices that are universally applicable.

\textbf{V. Literature Review Methods and Results}

We performed a PubMed search from January 2000 through February 2016 using the search terms: “serious gam*,” OR “gaming,” OR “virtual simulat*” OR “video game,” AND “healthcare,” OR “education.” Two independent reviewers reviewed all abstracts to select appropriate articles. In the event of disagreement, both reviewers reviewed the full article, and conflicts were resolved by consensus. In addition, we searched reference lists of relevant articles. We included reviews, meta-analyses, and original articles reporting results of games designed to teach knowledge, behavior or skills to
healthcare providers, excluding augmented reality and surgical simulator tools that involved devices that were not available for use on a computer or gaming console (i.e. laparoscopic surgical trainers).\textsuperscript{47} We excluded articles describing serious gaming used for education of patients, K-12 students or non-medical fields, although representative papers were read to gain a broad understanding of serious gaming applications. Figure 3 depicts our search strategy and key findings. 1048 articles were identified, and after excluding those based on our exclusion criteria, we included seven review articles and 77 original articles describing 69 serious games designed for teaching medical knowledge, behaviors or skills.

\textbf{Figure 3.} The search strategy and findings from the literature review.

Youngblood \textit{et al.} describes a framework for assessing new technologies in medical education and classifies studies by type of assessment.\textsuperscript{48} This framework is adapted from Kirkpatrick’s model of program evaluation which organizes potential methods for assessing educational interventions into levels of increasing sophistication: participant
reaction, learning improvement, clinical behavior change and outcome results.\textsuperscript{49} We classified the serious gaming studies we found based on the type of outcome assessment strategies, using Youngblood’s framework as listed below:

1. Robustness of System (n=44)
2. Review by content experts (n=44)
3. Usability testing (n=44)
4. Validity testing (n=7)
5. Assessing learning outcomes (n=34)
6. Integration into curriculum (n=8)
7. Transfer of learning to clinical practice (n=1)

Many studies investigated more than one type of outcome. Table 1 (appendix A) describes each serious game and study results, and categorizes each by the type of outcome assessed.

\textit{Studies describing the development of the serious game: system robustness, review by content experts, and usability testing}

We identified 77 studies that described development of serious games. Ten studies describe approaches to game structure, design challenges, educational content, pedagogical elements, and interactive components, but reported no outcomes.\textsuperscript{19,36,50-58} Eight studies compared two different designs of a serious game, showing that increased cognitive load within the game led to worsened scores and different patterns of user activity; hints and interactivity led to higher usability scores; learners performed better when the game was supplemented with traditional teaching methods such as lectures and small-group discussions; clustering of questions resulted in worsened performance; incorporating competition improved performance; and including pre-training within the game led to improved performance in participants, respectively.\textsuperscript{58-65} The other studies demonstrated high user satisfaction (n=37),\textsuperscript{16,21,24,35-36,44,46,59,64,66-93} high formal system usability scores on a Likert scale with users reporting the games to be realistic, educational, user-friendly, and engaging (n=12),\textsuperscript{17,21,61,66,67,70,83,87,88,92-94} and increased self-perceived knowledge and comfort with the material after exposure to a serious game (n=5) without a comparison.
One study assessed user self-efficacy and situational awareness, finding that these two variables correlated with user concentration and increased through serious gaming.\textsuperscript{77}

Five studies compared the serious game to conventional lecture or self-study, and found that users rated the serious game as more informative and preferable, with increased perceived understanding of content, help with learning, and enjoyment of learning compared to self-study or didactic lecture.\textsuperscript{66-72,87} Two studies that compared the serious game to conventional lecture or self-study found similar scores regarding self-assessment, knowledge reinforcement and knowledge acquisition.\textsuperscript{91,93}

**Studies describing validation of the serious game**

Seven studies included a validation component in the assessment of their serious games. Six studies found significant differences in multiple-choice question scores on game cases between medical students, interns, residents, equipment specialists, and attendings, demonstrating that their game was able to discriminate skill level,\textsuperscript{18,58,70,96-99} and one found that the referral rates by emergency room physicians playing their game were similar to those described in the literature for actual clinical practice in emergency medicine.\textsuperscript{58}

**Studies assessing learning outcomes**

Twelve studies assessed knowledge gain using pre- and post-testing without comparison to a control group. Eleven showed significantly improved post-test multiple choice scores compared to pre-test scores,\textsuperscript{24,38,58,59,62,69,78,83,85,100,101} while one showed no significant difference.\textsuperscript{102} Four studies looked at timing of intervention and retention. Two studies showed that refresher training closer to assessment resulted in higher scores.\textsuperscript{100,103} Two studies found that at 3 months post-testing, participants showed significantly increased scores compared to pre-testing, although lower scores compared to initial post-testing.\textsuperscript{24,104}
Twenty-one studies compared serious games to conventional educational modalities including: self-study (n=10), didactic lecture (n=7), live simulation (n=3), and self-study and live simulation (n=1), using multiple-choice questions or live simulation testing. Of the ten studies that compared serious games with self-study, five studies showed that serious games resulted in significantly better scores,\textsuperscript{37,71,101,103,105} three showed a trend favoring the serious games,\textsuperscript{18,99,102} and two studies found no difference between groups.\textsuperscript{72,106} Seven studies compared serious games with didactic lectures, with three studies demonstrating significantly better scores in the game group,\textsuperscript{38,63,107} one study demonstrating significantly better scores in the didactic group,\textsuperscript{101} and three studies finding no difference between groups.\textsuperscript{68,83,104} Three studies compared serious games with live simulation; one study found significant results favoring the serious game,\textsuperscript{106} another found non-significant results favoring the serious game\textsuperscript{87} and the other found no difference between groups.\textsuperscript{108} One study compared knowledge gain between serious game, live simulation, and self-study immediately post-intervention and at three weeks post-intervention.\textsuperscript{44} Self study had the lowest scores overall compared to the game or simulation groups, but there were mixed results depending on testing modality and time of testing, with neither the game nor simulation group showing consistent or sustained increase in scores compared.\textsuperscript{44}

**Studies assessing integration into curriculum and transfer of learning into clinical practice**

Eight studies assessed serious games with integration into a curriculum.\textsuperscript{68,72,73,82,83,102,109,110} No studies found a significant difference for the serious game group compared to control. One study assessed transfer of learning into clinical practice, finding a small but significant reduction in patient time to blood pressure target when physicians were exposed to the serious game.\textsuperscript{105}

**VI. Literature Review Conclusions**

Although the use of serious gaming in medical education is expanding greatly and offers a theoretical benefit over traditional educational modalities for the adult learner, clear evidence of superiority of this educational tool compared to traditional methods has not
been shown in current studies. Studies that assessed learning outcomes showed mixed results, with over half of the studies showing significantly increased efficacy for serious games versus conventional methods, and an additional third of studies finding insignificant trends towards improved learning outcomes with serious games compared to other methods. Very few studies investigated knowledge retention after the intervention period. The heterogeneous composition of various games, small sample sizes and varied study designs likely contribute to the variable results in current studies. Easy usability, increased satisfaction with, and preference for serious games were reported, suggesting that learners enjoy the game format. However, few studies compared different approaches to educational design of serious games, and more work is needed to establish optimal game design and pedagogy. Additionally, gaming technologies are rapidly evolving, and ongoing research will be necessary to study these newly developing modalities.

The number of published studies about serious games is rapidly increasing. 30 serious games were identified in a serious gaming review published in 2012\textsuperscript{111}, 42 were identified in a review published in 2014\textsuperscript{113}, and we identified 77 in our review through February 2016, representing nearly a doubling in studies in the past year. Like previous reviews that discussed the levels of Kirkpatrick and validation of serious games, we found that most studies described development and qualitative assessment.\textsuperscript{111-113} However, compared to previous reviews, an increasing number of studies have assessed validation, knowledge gain, and integration into curriculum. Furthermore, we found one study that assessed application of knowledge from serious games into clinical practice.\textsuperscript{105} Future studies should focus on the higher levels in the Youngblood framework, including assessment of knowledge gain, knowledge retention, integration into a curriculum, and application to clinical practice.

Another area that requires further study is the cost-effectiveness of serious gaming. One study conducted a comparative cost assessment between serious gaming and live, manikin-based teaching, and showed that the overall cost and logistical planning of the serious game group was significantly lower compared the simulation group.\textsuperscript{44} While
serious games and virtual environments share many benefits with live simulation, manikin-based learning requires trained instructors for debriefing, expensive manikins and technology, and ongoing bioengineering support for maintenance. Furthermore, it can be challenging to schedule instructors, participants, technical support and locations for live simulation learning. Considering that most studies assessing and comparing educational tools find similar efficacy,\textsuperscript{2,3,37} as did over half of the studies in our review, if serious games may be quite valuable by offering a relatively lower cost modality that yields similar educational efficacy to live simulation. Future studies should strive to elucidate the relative costs of different teaching strategies in order to obtain a more complete comparison.

Additionally, not all topics may be suitable to teaching using serious gaming; some would be better taught with another educational modality. So another goal of future studies should be to identify those subjects best taught with serious gaming. Along these lines, in the era of emphasis on evaluation of trainees based on clinical competency, serious gaming may serve to augment learning in the continuum of clinical competency, but is not intended to replace the current teaching structure. Clinical competency requires a well-thought out plan to teach core knowledge, clinical reasoning, procedural skills, teamwork, and translation to patient care, as well as integration of many modalities including didactic and theoretical teaching, virtual and live simulation exercises, standardized patients, and real patient encounters.\textsuperscript{2,39}

Combining serious games with traditional teaching strategies may be a promising way to take advantage of new multimedia technologies as well as the educational elements and motivation inherent in gameplay to enhance learning. Serious gaming allows practice prior to real patient experiences, and can allow the learner to identify and improve areas of weakness. Additionally, with changes in duty hours and the random nature of medical cases, serious gaming allows trainees to achieve elements of clinical competency that would not likely be achieved solely depending on real patient encounters. By incorporating game-based learning within traditional medical education, other teaching strategies can be used in a more targeted and efficient manner to
explore areas of weakness and to target those elements of learning that cannot be simulated virtually.

Despite the increasing use of serious games, the design and development of serious games for the education of health professionals is highly variable.\textsuperscript{111-113} Deterrents to the widespread development of serious games in medicine are cost, development time, and the need for expertise in gaming and technology.\textsuperscript{17,51,61,111-113} Often, clinician teams must partner with software development teams to create serious gaming resources, with each team offering a different skillset and working language. Incorporating best practices from educational pedagogy and software development, while following a structured approach, may help these teams work together, decreasing development costs and improving the quality of serious games.

In software development, wireframes and prototypes are used for visual communication and design of the structure, functionality, learner interface, and positioning of an application.\textsuperscript{114,115} Software prototyping is the process of producing a series of partial systems early in the development cycle to optimize efficiency.\textsuperscript{114,115} This method has been shown to enhance team communication and reduce the risk of misunderstanding by facilitating discussions through visuals, resulting in improved and cost-effective product design.\textsuperscript{114,115} Formal usability testing is often conducted following the development of a finished prototype, and many strategies for testing have been described and validated.\textsuperscript{114-119} Two methodologies for formal usability testing relevant to serious game development are Think Aloud Protocol testing and System Usability Scale (SUS) surveys.\textsuperscript{117,118} Think Aloud Protocol is a validated tool for product usability testing that involves observing subjects thinking aloud while performing tasks and interacting with the product.\textsuperscript{118} Think Aloud Protocol provides a structured technique for qualitative data acquisition and analysis, helping to reveal the thought processes of the consumer or learner and allowing for identification of usability issues.\textsuperscript{118} The SUS is a widely-used usability testing scale that assesses the ease of use of a product.\textsuperscript{119} The SUS includes ten easily administered questions, each given a score from 1 to 10. The responses are summed, reporting a single number (range from 0 to 100), with a score of 70 or greater.
signifying acceptable product usability. SUS scores can be trended over time to detect changes in product usability.

Many studies describe various clinical and educational frameworks for their serious game development, but the technical aspects of development are highly varied and rarely reported. Davids et al. describe a development process utilizing wireframes, iterative prototyping, SUS and qualitative feedback used to create an acid-base game. They report budget issues, communication difficulties and misaligned expectations between clinicians and developers as important challenges encountered during the process, which are challenges that have also been reported by others. A recent serious gaming review by Wang et al. concludes that for serious gaming to continue growth within medicine, development, evaluation and distribution frameworks need to be constructed.

VII. Serious Gaming for Pediatric Peritoneal Dialysis
Peritoneal dialysis (PD) is used in over half of children with dialyzed end-stage renal disease (ESRD) in developed countries. In developing countries, PD remains the predominant form of both acute and chronic pediatric dialysis. Despite this need worldwide, a recent study found that in the United States, renal fellows do not receive appropriate training in chronic PD, and others have shown that globally, there is a lack of clinicians trained to properly provide PD for children with ESRD.

Interest in nephrology as a career choice has declined in recent years, with medical students reporting nephrology topics as too complex and irrelevant. Nephrology is just one of two internal medicine subspecialties with a decrease in fellowship applications since 2002. In response to this declining interest, the American Society of Nephrology (ASN) formed a Task Force on Increasing Interest in Nephrology Careers, whose recommendations include the creation of novel educational tools that make nephrology more attractive to trainees.
Studies have shown that e-learning technologies and strategies are effective at teaching medical education topics, including within nephrology.\textsuperscript{127,128} As discussed above, serious gaming is one such technology that takes advantage of a structure that is well-known and liked by millennial learners, while incorporating interactivity, competition, and adult learning theory principles.\textsuperscript{111-113} Serious games provide a scalable, convenient method for users to practice skills in a safe environment with directed feedback and individualized control of pace and timing of learning.\textsuperscript{111-113} Thus, serious gaming may be particularly suited to teaching complex topics, such as PD.

Two online virtual nephrology educational resources have previously been developed and were identified. The first is an Internet-based patient case simulator that includes text with multiple-choice questions and teaches the following topics: principles of dialysis, hyponatremia, and acid-base abnormalities. William and Huang demonstrated increased learning with these patient cases.\textsuperscript{127} The second is an online virtual hemodialysis simulator, modeled after a specific vendor brand and available with subscription, and which includes the opportunity for learners to see what happens inside of a hemodialysis machine.\textsuperscript{128} No formal assessment of the simulator was described in the study.

We were unable to find any publications about serious games teaching about PD. In an online search, we identified video- and text-based teaching tools, as well as quiz-based games, about PD, but we were unable to find any virtual simulators or interactive serious games teaching PD. Thus, given this is such an important topic for many patients and clinicians, our goal was to develop a serious game to serve as a stand-alone educational resource to teach all elements of managing a child on PD, including physiological concepts of dialysis, setting and adjusting the prescription, assessment of patient and dialysate, monitoring and responding to patient variables and laboratory results, administering medications, and identifying complications from device manipulations. To develop the VPDS, we created a structured development framework, aimed to streamline the process and reduce some of the challenges described by other serious game developers, including communication and aligning expectations. Here, we
describe the development of our virtual peritoneal dialysis simulator (VPDS) including our iterative framework, educational approach, description of the simulator, results of the formative evaluation, and results of the initial release.

VIII. Methods
This project and its component analyses were approved for exemption by the Boston Children’s Hospital Institutional Review Board. The VPDS was developed in 12 months by a team of subject matter experts (SMEs including three pediatric nephrologists from the United States and South Africa, a pediatric intensivist, a third year pediatric resident, and a fourth year medical student), two medical animators, and an application developer (Genuine Interactive). The interprofessional and geographically diverse group promoted development of medically diverse simulated patients for the education of learners in different settings. The team met weekly, either in person or through phone meetings, alternating meetings with either the application developers and SMEs together and the SMEs only. The development was conducted in stages that derive from best practices in software design, as below (Figure 4).\textsuperscript{115-119} During the development phase, components were presented to the SME team, feedback was provided, and changes were iteratively incorporated.
**Figure 4.** The development process, including design, development and and iterative formative evaluation steps.

**Knowledge Transfer:** As one of the key challenges previously described was difficulty conveying medical knowledge to non-medical developers, our first step was to orient the application developers to the process of PD. The SMEs demonstrated how to perform PD on a manikin simulating: PD machine set-up, initial prescription selection, dialysate adjustments, troubleshooting common problems, and clinical assessment of the patient. The application developers asked questions, and took notes and pictures for reference.

**Content Production:** An outline of the knowledge guide was created and approved by the SMEs, and then text was written and peer-reviewed by the group. Short animated videos were produced by the SMEs and animators. Tactic and case “storyboards” were
collectively scripted, and patient animations were created. Once the content was completely developed, it was delivered to the application developer.

**Learner Experience Mapping:** The simulator interface and learner experience were collectively designed by the SMEs and application developer with a focus on realistic design elements that mimic patient care.

**Wireframes:** The application developer created a “wireframe” illustration of the proposed composition and functionality for the simulator, incorporating design and learner experience concepts from the previous steps in the preparation and design phase. After review by the SMEs, revisions were made, and a “clickable wireframe” was drafted, allowing for testing of functionality and learner experience.

**Prototype:** A fully interactive and styled prototype was built using Flash and the Adobe Air software program. With the prototype established, the feedback and scoring systems were designed by the SMEs and implemented by the application developer. These systems included points, physiologic response and text-based feedback assigned for all possible learner actions. The prototype underwent several rounds of review and feedback by the SMEs, and an iterative prototype for testing was generated.

**Formative evaluation:** Formal usability testing of the iterative prototype was conducted using structured scripts, developed based on evaluation methods used in other industries including engineering and software and web design.\(^{115-119,130,131}\) Testing was conducted in four rounds over four weeks, with thirteen subjects undergoing Think Aloud Protocol testing, a system usability scale (SUS) survey, a Likert-scale survey, and an open-ended questionnaire.\(^{115-119,130,131}\)

During Think Aloud Protocol testing, each subject used the simulator, and a SME observer gave prompts to assess key aspects of the design, content and functionality. Each session lasted roughly one hour, during which the observer recorded and categorized subject comments as content edits, learner interface edits, and bugs. Next,
the SME observer administered a SUS survey verbally and recorded responses.\textsuperscript{115-119} We modified the SUS, replacing the word “system” with “VPDS”. A qualitative questionnaire included five Likert-scale rated statements to assess usefulness, enjoyment, interest in future use, clarity of directions, and utility of feedback. Last, a series of open-ended questions included questions regarding optimal audience, most useful and least useful aspects of the simulator, and suggestions for changes to both content and usability.

After each cycle of testing (3-4 subjects per cycle), feedback was incorporated into the next prototype. This process was repeated in four plan-do-study-act (PDSA) cycles (Figure 4).\textsuperscript{115-119,130,131} The subject number and cycle number were chosen based on estimates of optimal study numbers for Think Aloud Protocol testing.\textsuperscript{130,131} Higher numbers have been reported to offer diminishing value in informing a development process.\textsuperscript{130,131}

\textbf{Release}: On January 28, 2016, the simulator was released for free access world-wide on OPENPediatrics (openpediatrics.org).\textsuperscript{132} Embedded analytics track usage, scores, and user actions, categorized and analyzed based on user profile. Qualitative data from surveys is also being collected. Optional multiple-choice case-based pre- and post-testing allows for assessment of knowledge gains. Of users who completed pre- and post-testing, statistical analyses were performed on non-zero values. Because of the small sample size that fit this criteria (n=14), we used the Wilcoxon signed rank test to test for a difference in the average pre- and post- test scores.

\textbf{IX. Results}

\textbf{Virtual Peritoneal Dialysis Simulator}

The VPDS allows the learner to practice performing PD in multiple clinical scenarios over varying pediatric ages (infant, child and adolescent) and disease states (acute kidney failure, chronic kidney failure, sepsis, peritonitis, congenital malformations), providing real-time feedback for learner actions. The simulator promotes a systematic approach in response to problems and complications that arise while a patient is being
managed on PD. The learner virtually diagnoses conditions and complications, manipulates the PD set-up and prescription, and administers medications. Learner actions include movement of fill bag and drain bags, clamping and unclamping of catheters, adjustments to cycle time, fill volume, and concentrations of electrolytes and dextrose in the dialysate. Medications include sodium supplementation, intraperitoneal antibiotics, and fibrinolytics. Learner actions respond to the patient’s vital signs, physical exam, and laboratory findings, with programmed pathophysiologica l changes in response to learner actions.

Incorporating one theory of adult learning, the Kolb Learning Cycle, the PD simulator contains three sections, which increase in interactivity and challenge as the learner progresses stepwise through the simulator (Figure 5). Specifically, the knowledge guide promotes abstract conceptualization, the tactics provide an opportunity for active experimentation to test their newly acquired knowledge, the case simulation offers the learner a concrete experience to synthesize their learning, and the feedback provides for reflective observation.
Figure 5. The PD simulator was built to take learners through the stages of the Kolb learning cycle.

1. **Knowledge guide**: A primer on PD that includes interactive text-based sections and some short videos, the knowledge guide is structured to teach basic concepts while offering pre-training that familiarizes the learner with the interface and work-flow of the simulator (Figure 6).

Figure 6. Screenshots of the knowledge guide, highlighting key features.
Learners must complete each section to “unlock” the next section before progressing. No scoring is provided here, but arrows help guide the learners through the appropriate actions. The knowledge guide contains the concepts and instruction needed to complete the subsequent sections of the simulator, and can be accessed at any time to reinforce learning. The knowledge guide is organized into the following sections:

- definitions (dialysis, osmosis, diffusion, convection, membrane properties)
- concepts (indications and contraindications, ultrafiltration, clearance, and infection control)
- prescription (sodium, potassium, dextrose, heparin, antibiotics, fill time, drain time, dwell time, cycle number, fill volume)
- administration (fill phase, dwell phase, drain phase, patient monitoring)
- complications and trouble-shooting (peritonitis, catheter obstruction, hyponatremia, hypokalemia, hyperkalemia, peritoneal catheter leak, poor ultrafiltration, impaired filling or drainage)

2. **Tactics:** This section is designed to train learners to utilize a structured approach to manage clinical problems and situations and builds on the information in the knowledge guide (Figure 7).
In short case-based scenarios, the learner identifies, diagnoses and solves common PD problems. To promote a systematic approach, after reading a patient history, the learner is asked to examine a simulated patient, assess laboratory results, fluid balance, and effluent. The learner then selects a diagnosis from a pull-down list. If correct, they proceed to manage the condition. If incorrect, one of three possible hints is given to guide the learner in selecting the correct diagnosis.

Learners must perform specific actions to pass each tactic. Points are awarded for correct and essential actions, and points are subtracted for harmful or unnecessary...
actions. Feedback guides learners if they do not perform the correct actions. To allow for reflective observation, a broad summary of the learning goals is provided, along with detailed learner-specific feedback for each possible action. The tactics address the following common PD scenarios:

- electrolyte abnormalities (hyperkalemia, hypokalemia, hyponatremia)
- mechanical complications (catheter obstruction, clamped catheter, inadequate fill bag height, inadequate drain bag height)
- patient-specific complications (dehydration, peritoneal catheter leak, peritonitis, poor ultrafiltration)

3. **Case simulations**: Here, the learner cares for a variety of simulated patients over a longer amount of clinical time, making decisions regarding diagnostics, testing, and treatment, and observing the impact of their decisions (Figure 8).
Figure 8. Screenshots of a case study, emphasizing the patient clinical scenarios and tasks that the learner must perform.

The goal of this section is to reinforce concepts taught in the knowledge guide and tactics, in a less directed and more realistic clinical experience. After learners select the dialysate prescription, the patient progresses with several complications and checkpoints. Time is advanced so that several days of a clinical scenario can be simulated over approximately 30 minutes. At each checkpoint, learners are scored and given detailed feedback on their actions in real time.
At each checkpoint, learners are scored and given feedback on their actions in real time. At the end of the case, learners are offered action-specific feedback, overall scores, and a summary of the learning objectives (Figure 9). Learners receive medals based on their score.

![Learner-controlled feedback includes a case summary as well as a scoring break-down by task and skill](image1)

Learners can click on tasks to see detailed action-by-action feedback

Once learners pass a case, they earn medals based on their scoring

**Figure 9.** Screenshots of the patient case feedback, which includes both conceptual summaries and interactive feedback specific to every learner action and inaction.

**Formative Evaluation**
Thirteen subjects (46% male, 54% female) volunteered to participate in the formative evaluation process (2 nephrology nurses, 3 medical students, 2 pediatric residents, 3 renal fellows, 2 pediatric critical care fellows, and 1 nephrology attending). Most subjects had taken online courses and used online simulators in the past, citing interactivity and realistic nature as positive qualities, and overly rigid rules and time needed to learn to use the tools as negative qualities. Rated on a scale from 1-5, average comfort level with technology was 4.23.

Edits decreased and user satisfaction increased over the course of testing and VPDS iteration. Between cycles, the total bugs identified, content edits, and learner interface (UI) edits all decreased (Figure 10). The mean 10-question SUS and qualitative questionnaire scores indicate high usability and satisfaction, as well as improvement in usability through the iterative process (Table 2).
Figure 10. Think Aloud Protocol testing results for each round of testing, organized according to total bugs, total content edits, and total user interface edits.

Table 2. System Usability Score (SUS) statements, average SUS scores out of 100 (with standard error), and post-testing survey questions with average ratings on a Likert scale from 1 to 5 (1 = strongly disagree; 5 = strongly agree).

<table>
<thead>
<tr>
<th>System Usability Score Statements</th>
<th>Average System Usability Score (Standard Error)</th>
<th>Post-testing Survey Questions (Targeted Design Questions) with Average Ratings*</th>
</tr>
</thead>
<tbody>
<tr>
<td>I think that I would like to use the VPDS frequently.</td>
<td>Round 1 75.833 (5.601)</td>
<td>How interested are you in using the VPDS in the future? 4.538</td>
</tr>
<tr>
<td>I found the VPDS unnecessarily complex.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I thought the VPDS was easy to use.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I think that I would need the support of a technical person to be able to use the VPDS.</td>
<td>Round 2 94.583 (3.024)</td>
<td>How would you rate your enjoyment of the VPDS? 4.923</td>
</tr>
<tr>
<td>I found the various functions in the VPDS well integrated.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I thought there was too much inconsistency in the VPDS.</td>
<td>Round 3 94.167 (1.179)</td>
<td>Was the feedback in the VPDS useful? 4.692</td>
</tr>
<tr>
<td>I would imagine that most people would learn to use the VPDS very quickly.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I found the VPDS very cumbersome to use.</td>
<td>Round 4 94.375 (2.232)</td>
<td>Were the directions clear? 4.577</td>
</tr>
<tr>
<td>I felt very confident using the VPDS.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I needed to learn a lot of things before using the VPDS.</td>
<td></td>
<td>How useful is the VPDS? 4.885</td>
</tr>
</tbody>
</table>

*Likert scale from 1 to 5 (1 = strongly disagree; 5 = strongly agree)

Feedback from the open-ended questionnaire was generally positive, with participants naming the interactive cases as the most useful aspect. Participants considered the simulator useful for residents, medical students, nursing students, and critical care and nephrology fellows early in training. Subjects stated that the knowledge guide was the least useful aspect (n=2) and the physical exam function was least user-friendly (n=3). Subjects asked for more free-play capabilities (n=3) and suggested an additional adaptation of the VPDS as a parent and family teaching tool (n=3). The knowledge guide, physical exam function and free-play capabilities were subsequently adapted. No participants found the simulator difficult to use, including those who indicated a weak level of computer literacy.

Open-ended feedback included the following:
“This is the most interactive simulator I have used.”
“Really well laid-out and easy to use. I love that the feedback is so thorough and immediate.”
“I can’t wait to use this for both nursing and medical students.”
“The UI is engaging, and the appearance is appealing; it makes me want to use it.”
“The content is so helpful and well-written.”
“It’s the best way to learn – you’re given training wheels… then your knowledge is tested, and if it's too hard, the training wheels are there to come back to.”

Release
From January 28, 2016 until March 31, 2016, the VPDS has been accessed by 223 users 342 times, with an average of 1.534 sessions per user. The users include attending physicians (40%), residents (18%), nurses (19%), fellows (13%), medical students (1%), and other healthcare professionals (9%) (Figure 11). Although the majority of users have been from the United States, users from 51 different countries have accessed the simulator (Figure 12).
Figure 11. Graphic representation of the different healthcare professional groups who have utilized the simulator since its release: attending physicians (40%), nurses (19%), residents (18%), fellows (13%), other healthcare professionals (9%), and medical students (1%).

Table 3. Users who have accessed the simulator, organized according to country, with 51 countries represented.

<table>
<thead>
<tr>
<th>Country</th>
<th>Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>75</td>
</tr>
<tr>
<td>Brazil</td>
<td>12</td>
</tr>
<tr>
<td>Argentina</td>
<td>9</td>
</tr>
<tr>
<td>Canada</td>
<td>9</td>
</tr>
<tr>
<td>India</td>
<td>8</td>
</tr>
<tr>
<td>Spain</td>
<td>8</td>
</tr>
<tr>
<td>Mexico</td>
<td>7</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>7</td>
</tr>
<tr>
<td>Pakistan</td>
<td>6</td>
</tr>
<tr>
<td>Romania</td>
<td>6</td>
</tr>
<tr>
<td>Malaysia</td>
<td>5</td>
</tr>
<tr>
<td>Australia</td>
<td>4</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>4</td>
</tr>
<tr>
<td>Turkey</td>
<td>4</td>
</tr>
<tr>
<td>Chile</td>
<td>3</td>
</tr>
<tr>
<td>Ecuador</td>
<td>3</td>
</tr>
<tr>
<td>Germany</td>
<td>3</td>
</tr>
<tr>
<td>Greece</td>
<td>3</td>
</tr>
<tr>
<td>Italy</td>
<td>3</td>
</tr>
<tr>
<td>Austria</td>
<td>2</td>
</tr>
<tr>
<td>Colombia</td>
<td>2</td>
</tr>
<tr>
<td>Ireland</td>
<td>2</td>
</tr>
<tr>
<td>Israel</td>
<td>2</td>
</tr>
<tr>
<td>Netherlands</td>
<td>2</td>
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<tr>
<td>Norway</td>
<td>2</td>
</tr>
<tr>
<td>Qatar</td>
<td>2</td>
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<tr>
<td>Singapore</td>
<td>2</td>
</tr>
<tr>
<td>South Africa</td>
<td>2</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>2</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>1</td>
</tr>
<tr>
<td>Country</td>
<td>Count</td>
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<tr>
<td>------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Finland</td>
<td>1</td>
</tr>
<tr>
<td>Guatemala</td>
<td>1</td>
</tr>
<tr>
<td>Haiti</td>
<td>1</td>
</tr>
<tr>
<td>Honduras</td>
<td>1</td>
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<tr>
<td>Hong Kong</td>
<td>1</td>
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<tr>
<td>Hungary</td>
<td>1</td>
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<tr>
<td>Jamaica</td>
<td>1</td>
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<tr>
<td>Korea, South</td>
<td>1</td>
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<tr>
<td>Latvia</td>
<td>1</td>
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<tr>
<td>Lebanon</td>
<td>1</td>
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<tr>
<td>Libya</td>
<td>1</td>
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<tr>
<td>Martinique</td>
<td>1</td>
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<tr>
<td>Nepal</td>
<td>1</td>
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<tr>
<td>New Zealand</td>
<td>1</td>
</tr>
<tr>
<td>Oman</td>
<td>1</td>
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<tr>
<td>Panama</td>
<td>1</td>
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<tr>
<td>Serbia</td>
<td>1</td>
</tr>
<tr>
<td>Uganda</td>
<td>1</td>
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<tr>
<td>Ukraine</td>
<td>1</td>
</tr>
<tr>
<td>Uruguay</td>
<td>1</td>
</tr>
<tr>
<td>Vietnam</td>
<td>1</td>
</tr>
<tr>
<td>Unspecified</td>
<td>2</td>
</tr>
</tbody>
</table>

The knowledge guide has a completion rate of 43% (96/223) with an average time spent of 60 minutes. The tactics have a completion rate of 41% (22/54) with an average time spent of 59 minutes. The cases have a completion rate of 61% (11/18), with an average time spent of 59 minutes. Of those who accessed each of the three cases, 85%-89% completed the case. Of the text-based sections in the knowledge guide which required scrolling in order to read the entire text, 47%-69% of users scrolled through the text. In pre- and post-testing, of the 14 subjects who completed both pre- and post-testing with non-zero values, a median difference of a 20-point increase in post-test scores (p=0.0015) was found.

**X. Discussion**

To our knowledge, the VPDS is the first serious game for teaching PD delivery and management. Building on a framework described by Davids et al.,\textsuperscript{17} we developed a three-phase responsive iterative development process that structures production and
decreases the challenges described by previous studies of serious games. Formative evaluation demonstrated high usability, interactivity, utility, and enjoyment.

Since its release, the simulator has been utilized by clinicians across fields and training levels throughout the world. The simulator has received positive feedback from users both in usability testing and since its release from informal correspondences. Users on average return for multiple sessions, indicating interest. Of those who are motivated to complete the sections, users spend an average of 59-60 minutes on each of the three sections, indicating high time-on-task, interest, and motivation for self-directed learning. The high percentage of users who scrolled through the knowledge guide text indicates that users are engaging with the simulator. Preliminary data from pre- and post-testing indicate knowledge gains, although the sample size is small to date.

We sought to incorporate elements from the serious gaming literature that promoted usability and learning. Although realistic and complex problems facilitate knowledge gain, learners may be overwhelmed and frustrated by technology that is not easy to use or problems that are too challenging. Thus, we utilized pre-training in the knowledge guide to familiarize the learner with the VPDS, requiring them to complete short tasks covering all elements of the simulator. This knowledge is then applied to more complex and challenging activities. Step-wise learning is supported, shaped around the Kolb Learning Cycle. Hints guide the learner to correct responses and actions in the tactics, and the learner can then apply this knowledge without hints in the cases section. The systematic approach promoted by the VPDS facilitates knowledge retrieval and application to clinical cases, while building analytical skills that avoid cognitive processing errors and assumptions in clinical reasoning. Immersion is encouraged through the virtual simulation of a realistic clinical environment, compelling cases, a high degree of interactivity, and natural user actions with predictable consequences. Action-specific feedback is provided in the tactics and cases to promote reflection, and competition is encouraged through medal acquisition.
To decrease medical content communication challenges and align expectations, we added a Preparation and Design Phase to our development process to share knowledge between the SMEs and application developer teams. We delivered clinical simulator content to the application developer prior to user experience mapping, transferring knowledge upfront. A clickable wireframe process was included to allow for changes to the learner experience before costly styling and full coding was completed, helping to reduce costs and development time. Scheduled meetings promoted accountability and required regular feedback between teams.

We also added a detailed iterative Formal Evaluation Phase to identify problems with and improve the simulator before its release. In this phase, Think Aloud Protocol methodology allowed for identification of usability issues, and SUS scores were used to monitor how iterations impacted product usability. We conducted several rounds of rapid PDSA cycles to improve the simulator. By conducting several rounds of testing with a small number of participants, we were able to efficiently identify bugs and usability issues without exhausting a large pool of testers or imposing a significant burden of testing time for the SMEs. Our three-phase development process incorporates best practices from the education, software design, and quality improvement fields,\textsuperscript{115-119,130,131} may help to improve communication and encourage more efficient and effective product development, and may be generalizable for future serious game development in the education of health professionals.

One limitation to our study is that our simulator was costly to develop (approximately $80,000 USD) because of the extremely high level of interactivity and realism that we desired. However, the development methodology is likely still generalizable to educators wishing to develop other serious games at a variety of budgets. This limitation emphasizes the important need for scalability and global distribution of resources such as the VPDS. Although serious games are initially costly to develop, as these resources are shared amongst clinicians worldwide, the cost per learner quickly decreases. This is an advantage over other learning strategies such as live simulation using mannequins, which continues to incur a high cost with each additional learner.\textsuperscript{44} Another limitation is
that the simulator was built using the English language. Thus learners that are not fluent in English will not be able to utilize this resource, and future work should translate this simulator to other languages, in order to increase its global applicability.

Another limitation is that during the Formative Evaluation Phase, the subject responses were given verbally to the direct observer. Subjects may have been less likely to voice negative feedback verbally, potentially elevating the SUS. However, the Think Aloud Protocol outlines a verbal and observed testing process, which encourages reflection and increases the likelihood of open-ended feedback, potentially enriching the data. An additional limitation is the small subject number for testing. However, the sample size used is standard practice for Think Aloud Protocol testing.115-119,130,131 Through small numbers of diverse testers undergoing PDSA cycles, not only did we show decreased edits with each round, indicating improvement, but we also found that proportionally fewer edits were related to technical issues and proportionally more comprised sophisticated content edits, which we believe allowed us to improve our simulator more effectively. We did see a higher number of bug and content edits seen in group 3, which was likely related to variability in thoroughness and technical experience of the small numbers of subjects.

Limitations in the assessment of the data since the simulator’s release include the small subject number available for testing of knowledge gains. Although this preliminary data indicates that users are learning from the simulator, knowledge will need to be assessed more systematically and formally. Furthermore, like all studies of internet-based learning tools, assumptions must by made regarding user interaction and engagement with the simulator. Although preliminary data such as time-on-task, clicking/interaction, scrolling, and repeated use, point towards engagement and interest with this teaching tool, this is an area that requires further exploration.

Despite showing some highly motivated users, the data also indicates a low completion rate for the simulator (both from start to finish, and for each individual section). The overall simulator completion rate is on par with completion rates for massive online
The next steps will include an evaluation of user experiences with the published simulator, followed by progressing through the steps in Youngblood et al.’s evaluation framework: validation and knowledge gains assessment. Future studies should focus on comparing learning from the VPDS with other educational modalities, and application of skills into clinical practice. More work is needed to assess cost-effectiveness of serious games in medical education, as the capacity to reach such a wide audience and the potential to reuse and adapt the existing format may make the VPDS a cost-effective educational modality. Based on feedback from the formative assessment, the simulator is currently being adapted as a patient and family teaching instrument, and its efficacy in this realm will also require further study.

**XI. Conclusion and Summary**

Serious games offer an opportunity to scale standardized teaching resources in medical education. Serious games have theoretical and demonstrated benefit over traditional teaching methodologies. They incorporate an appealing and interactive interface to target Millennial learners, and the gaming aspect introduces motivational factors and cognitive scaffolds to promote learning. Because time is manipulated and reality is augmented, complex theoretical, technical, and clinically practical concepts such as PD can be taught. Adult learning theory principles are maximized in this teaching modality that offers learners accessibility to education when it is convenient and clinically useful, self-pacing and capacity for repetition, and learner-controlled, real-time, specific feedback. Automated scoring and feedback specific to user actions allow knowledge gains while decreasing demand on educators.

Prior to this report, no serious game existed for teaching clinicians PD concepts and management practices. By incorporating best practices from fields outside of medicine
and medical education, we developed a responsive iterative process to optimize the development of the VPDS. The VPDS caters to a variety of learning styles by incorporating narrated videos, text-based content, and interactive components that include scoring and feedback, and incorporates concepts that are applicable across resource settings. Formative evaluation demonstrated indicated high usability, interactivity, utility, and enjoyment with the VPDS, and results since its release indicate interest and widespread use globally, as well as time-on-task, interactivity, and engagement.

The VPDS has the potential to scale knowledge exchange globally and teach PD in an engaging, relevant and efficient manner. Our next steps will be to continue to track usage and knowledge gains, and to explore reasons for partial completion of the simulator. Furthermore, our next stages of evaluation will include progressing through the steps in Youngblood’s framework.48 Future studies should compare learning from the VPDS with other educational modalities, and study the application of skills learned from the VPDS into clinical practice. Lastly, the cost-effectiveness of the VPDS should be studied. Based on feedback from the formative assessment, the simulator is currently being adapted as a patient and family teaching tool.

XIII. Acknowledgments and Disclosures

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Other Disclosures: None reported

Ethical Approval: This project and its component analyses were approved for exemption by the Boston Children’s Hospital Institutional Review Board.

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