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Developing Virtual Reality Simulations for Office-Based Medical Emergencies

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Published In/Presented At

Lemheney, AJ., Bond, WF., Paden, JC., LeClair, MW., Miller, JN., Susko, MT., (2016). Developing Virtual Reality Simulations for Office-Based Medical Emergencies. *Journal of Virtual Worlds Research, 9(6), 1-18. DOI: http://dx.doi.org/10.4101/jvwr.v9i1.7184.*

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This article is available at LVHN Scholarly Works: https://scholarlyworks.lvhn.org/education/107

Journal of
Virtual Worlds Research
jvwresearch.org ISSN: 1941-8477

Assembled 2016

March 2016
Volume 9 No. 1



(c) Art by Tzafnat Bekin Shpak

Volume 9, Number 1
Assembled 2016 (1)
April 2016

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Journal of Virtual Worlds Research
jvwresearch.org ISSN: 1941-8477

Volume 9, Number 1
Assembled 2016 (1)
April, 2016

Developing Virtual Reality Simulations for Office-Based Medical Emergencies

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Abstract

Virtual reality simulation may significantly benefit a geographically dispersed learner demographic in the medical outpatient setting. Our research used an immersive virtual reality platform as a novel way to recreate high-risk medical scenarios targeted for office-based emergencies. Using a design-based research approach we designed virtual-reality-based simulation scenarios to prepare interprofessional office personnel for emergencies. Learners were connected using laptop computers, via a browser interface, with learner controlled team member avatars and educator controlled patient avatars. The virtual environment was modeled after a multi-provider healthcare office setting in a large suburban health network. Evaluation occurred via post-event surveys and feedback transcribed from video recordings and debriefings. Three office-based emergency scenarios were created (chest pain, respiratory distress/allergic reaction, and suicidal risk), with progressively smaller changes to the virtual environment with each iterative improvement. In total, 18 individuals representative of a typical outpatient office interprofessional care team participated in the study. Qualitative design-related feedback from participants and faculty improved the educational environment, artifacts, and scenarios. Participant feedback was overwhelmingly positive and enthusiastic about the use of virtual reality-based simulations to explore teamwork, build scope of practice, and rehearse infrequently used clinical skills. We successfully created novel outpatient virtual reality simulations in a first-person-perspective virtual environment. Pilot testing revealed successful rapid development, implementation, and participant orientation, with the ability to present learning opportunities. Future efforts will include assessments and attempt to overcome development barriers by switching to a more versatile platform.

Acknowledgements

Special thanks to The Dorothy Rider Pool Health Care Trust, who made a grant available for this research.

1. Introduction

Virtual reality simulation is used in aviation training (Duburguet & King, 2015), software engineering (Elliott, Peiris, & Parnin, 2015), military (Allen & Demchak, 2011; Cukor et al., 2015; Hamstra, Brydges, Hatala, Zendejas, & Cook, 2014; Rothbaum et al., 2014), and nuclear power systems training (Zhang & Zhang, 2013) among others. Virtual reality simulation in healthcare is growing rapidly and holds promise for maximizing access and minimizing the costs of training simulation (Ghanbarzadeh, Ghapanchi, Blumenstein, & Talaei-Khoei, 2014; Ma, Jain, & Anderson, 2014). Early successes include; procedural simulation (Cates, Lönn, & Gallagher, 2016; Cates, 2007; Gallagher, 2004; Ridgway et al., 2007; Satava, 2005; Van Herzeele, 2007), disaster management (Ingrassia et al., 2015; Pucher et al., 2014), objective structured clinical examinations (OSCEs) (Andrade et al., 2012), infrequent and rare complications (Brydges, Hatala, Zendejas, Erwin, & Cook, 2015; Ziv, Wolpe, Small, & Glick, 2003), patient safety (Arora et al., 2014; Brewin, Ahmed, & Challacombe, 2014; Cheung et al., 2010; Kunkler, 2006; Reznek, Harter, & Krummel, 2002), teamwork (Alverson et al., 2008; Dev, 2007; Rudarakanchana, 2014), community care (Arya, Hartwick, Graham, & Nowlan, 2012), exploring medical error (Barry, Reznich, Noel, & WinklerPrins, 2010; Patel, Kannampallil, & Shortliffe, 2015), behavioral health (Pensieri & Pennacchini, 2014), patient education and engagement (Davis & Calitz, 2014; Swicegood & Haque, 2015), handoff communications (Berg, Wong, & Vincent, 2010), and replacing live patient encounters (Conradi et al., 2009; Cook, Erwin, & Triola, 2010; Czart, 2014; Danforth, Procter, Chen, Johnson, & Heller, 2009; Edelbring, Dastmalchi, Hult, Lundberg, & Dahlgren, 2011). Underlying these types of virtual reality is social participation as a key element creating the dynamic learning environment. However, until recently, most designs have been targeted to specific learner audiences rather than interprofessional healthcare teams.

Early virtual reality platforms used to meet educational objectives in healthcare include Second Life, Virtual Heroes, OpenSim, Active Worlds, Kaneva, and Onverse. Some platforms, such as Second Life, were designed initially with educational, social, and commercial potential; others were built upon video game engines and/or with plans for serious games; still others were created specifically for simulations or the creation of virtual patients. Serious gaming has grown rapidly in healthcare, with many early successes captured in recent reviews by Barsom, et al. (2016) and Graafland et al. (2012).

We began development of virtual environments for healthcare simulation with pilot work in Second Life. Our first clinical case scenario presented an ST-segment elevated myocardial infarction, a critical heart condition requiring immediate action, in the inpatient setting. We found that our learners, who consisted of nurses ranging in age from 25-60 years old, struggled with the complexity, ease of use, and stability of the interface. This, combined with other technical complications, led us to move to the AvayaLive Engage platform, which was designed for web-based virtual meetings rather than gaming or simulation. However, it afforded us a very simple web-based user interface, healthcare-specific avatars for the learner, stable communications methods such as voice over internet protocol (VOIP), and the ability to custom-build interactive 3D objects.

Our research goal was to create an easily accessible virtual outpatient office-based environment with an intuitive and scalable interface. We intended for the environment to support team interactions

and interprofessional education. The intention was for healthcare learners to control their individual avatars, and for the patient avatar to be controlled by a confederate actor. The virtual environment had to support the observer(s) viewing and assessing provider and nurse progress during the scenarios and their completion of learning objectives through either recorded markers or direct visualization. See Figure 1, which provides a screen capture of the provider and nurse interacting with the patient actor.



Figure 1. Provider and nurse interacting with the patient actor in the virtual medical office

We chose to focus on office-based emergencies because of the need for geographically dispersed education, the opportunity for large numbers of learners, and national trends toward more, and more complex, outpatient care. Due to fortuitous timing, our large multi-hospital, multi-office healthcare system planned to roll out a standardized emergency cart for office-based emergencies. The red standardized emergency cart can be seen in Figure 1. The cart contains essential supplies, medications, and equipment (drug box, oxygen tank, and airway management equipment) to respond in an emergency situation. Thus, this environment created a perfect opportunity to introduce the standardized cart. Three high-risk, low-volume case scenarios were developed targeting the most commonly occurring office-based medical emergencies.

2. Method

This research was given exempt status by the Intuitional Review Board (IRB). Exempt status was designated because nothing in the proposed research protocol differed from standard data that would be gathered, as well as approaches and strategies used, when examining new teaching and learning technology tools at the institution where this research was conducted. We created a multidisciplinary study group that included: a lead designer and project manager with expertise in educational technologies, an instructional technologist skilled in learning design, a social media developer skilled in rendering 3D objects, a physician with expertise in emergency medicine and simulation, and nurse educators with expertise in the training and development of outpatient clinical personnel.

We chose an iterative design-based approach due to the novel and untested nature of this virtual platform for simulation-based education, the newly developed scenarios, and from the perspective of virtual education, a new interprofessional learner group. See Figure 2, which describes the development framework for both the scenarios and environment simultaneously. Design-based research deals with experimental design principles and the features particular technologies offer for practical application (Barab & Squire, 2004; Herrington, McKenney, Reeves, & Oliver, 2007). The exploratory nature of this

design-based research fully examined the combination of elements and features within the design, providing us with a practical way to define theory as well as apply it to the design strategy (Reeves, Herrington, & Oliver, 2005). Design-based research is also appropriate when the research team and participants become actively engaged in causing the changes under study.

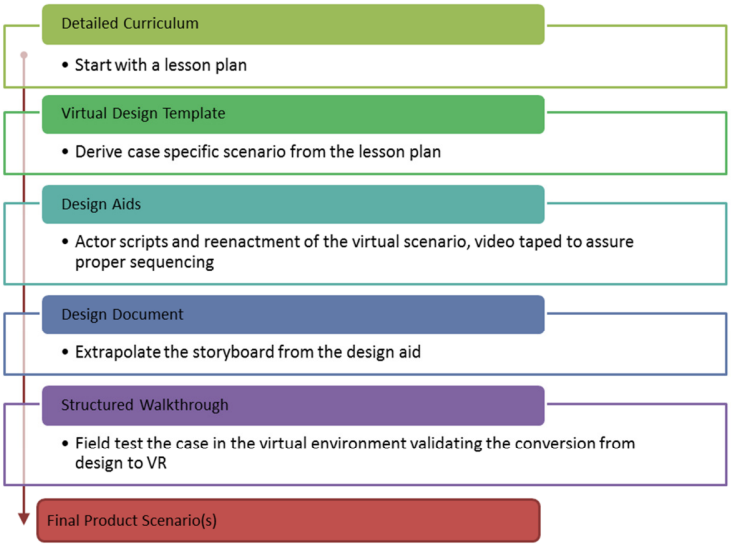


Figure 2. Development framework for both the scenarios and virtual environment

As a development strategy, the design team acted out the case scenarios in the simulation center with standardized patient actors, filmed them, and used clips/still photos to create our storyboard and share our design needs with digital asset developers. Video recording the new case scenarios also served as a means of validating the scenario sequence and critical actions as well as engaging the interdisciplinary design team, providing first-hand experience with the design in action.

All participants were volunteers and included physicians, advanced practice clinicians, registered nurses, nursing assistants, and unlicensed office registrar staff. Participants signed consent forms to include their data and record their experiences. The sampled pilot population included the clinical care team from one family practice outpatient office location. Clinical experience ranged from 1 year out of school to over 20 years of practice. Participants were told from the outset that their feedback would be critical to improving the virtual environment and the scenarios. The total number of unique participants, some of whom engaged in multiple scenarios, as described in Table 1. A team leader who was either a physician or advanced practice clinician (nurse practitioner or physician assistant) from their site led their team through the scenario(s). If a provider-level clinician was unavailable, the next level clinician was expected to take the lead role. All tasks were expected to be completed by the available team members. Tasks ranged from acute medical interventions such as giving medications to calling emergency medical services and recording and sharing the patient's medical record. Participants were encouraged to interact as they would normally in a clinical environment, including any safety-oriented communication, checking the electronic medical record, documenting and sharing encounter information, calling for help, and activating emergency services.

Table 1. Participant demographics

Demographics	
18	Participants
2	Male
16	Female
21-60	Age range (mode 41-50)
2 (11%)	Provider
2 (11%)	Nurse
3 (17%)	LPN
5 (28%)	Office staff
6 (33%)	Medical Assistant
9 (50%)	Prior game experience
5 (28%)	Prior VR experience
16 (89%)	Prior office based emergency experience

Three initial virtual reality case scenario topics and learning objectives were chosen based on quality improvement event data from our network's office locations and national trends regarding the most commonly reported medical emergencies (Dachs, Back, & Glick, 2007; Lehigh Valley Health Network, 2012). The topics, in order of development, were chest pain, allergic reaction, and suicidal risk. Scenarios were built using a simulation case development template that was originally created by the Society of Academic Emergency Medicine Simulation Academy, subsequently adopted by the MedEdPortal repository, and customized by our study group specifically for the development of virtual cases (D. Alverson, Caudell, Goldsmith, & Riley, 2015; MedEdPortal, 2013). Each scenario took approximately 10 minutes to run; another 15 minutes were allocated for debriefing, with 5 minutes for post-simulation evaluation. For the first iteration, the initial selection of key setting elements and scenario content was based on a composite design from prior proof-of-concept projects and suggestions from recent literature. Our initial design principles appear in Table 2.

Table 2. Initial design elements determined by prior proof-of-concept projects and literature review

Design Element	Description
Situated learning	Familiar context that is recognized by the participant
Debriefing	Activity leveraging the interactions of participants
Navigation	Sequenced directions and navigation aids
Identical elements	Accurate visual representations of clinical artifacts
Stimulus variability	Variety of relevant stimuli as found in the clinical setting
Feedback	Prompts to facilitate progression through the activity
Social context	Collaborative synchronous participation of the players

2.1 Virtual Environment

The virtual environment was a computer-generated representation of the participating Lehigh Valley Health Network (LVHN) office practice site, providing sufficient details, artifacts, and spatial relationships of common objects that were appropriately scripted to behave as their real-world counterparts would. For example, by clicking on the electrocardiogram (ECG) machine, it would show leads on the patient, and then by clicking on the ECG screen, that patient's ECG image would pop-up full screen. The modeled site was a multi-room, multi-provider suburban family practice outpatient site.

All rooms and the building exterior were modeled and traversable, but only three rooms had educational functionality built into them. Refer to Figure 3 for a schematic of the virtual medical office design.

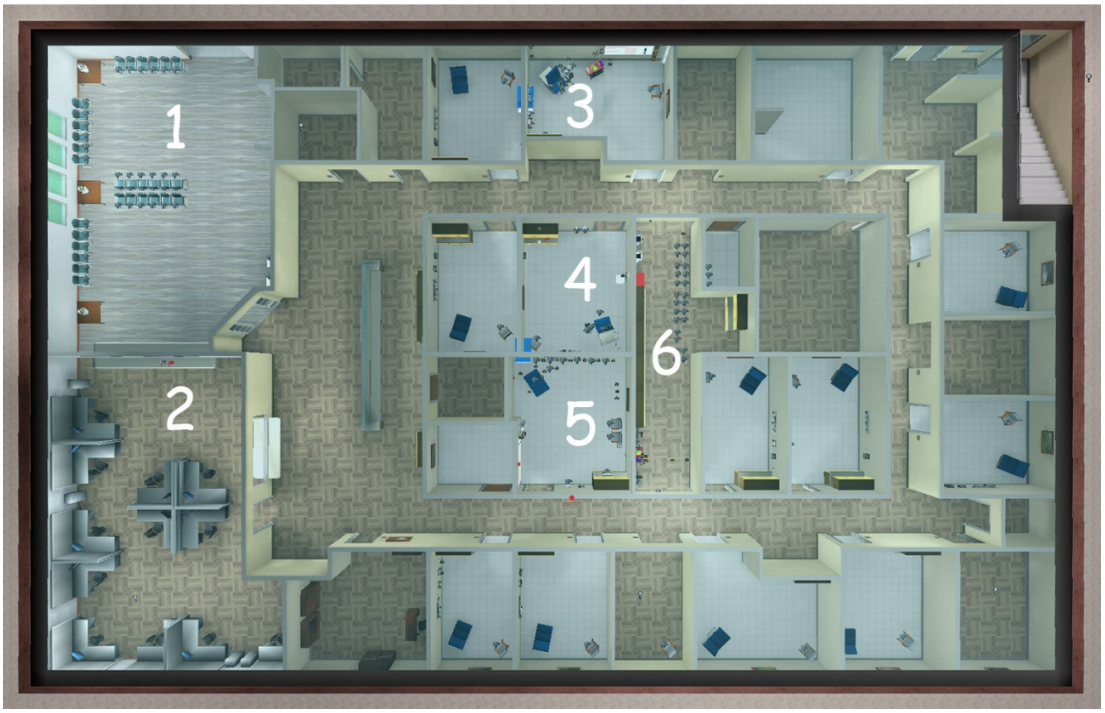


Figure 3. Schematic of the virtual medical office design
The labels represent (1) waiting room, (2) staff offices, (3) exam room for the respiratory emergency scenario, (4) exam room for the behavioral health emergency scenario, (5) exam room for the cardiac emergency scenario, and (6) medical equipment storage area where the outpatient emergency cart, mobile blood pressure cuff, pulse oximeter, and ECG machine were located.

The AvayaLive Engage platform offers simplicity as strength. AvayaLive Engage is a browser-based multi-user virtual environment focused on providing an online collaborative experience through the user-controlled avatars and features such as voice and text communication, point and click interactivity with the environment, presentation capabilities, and collaborative web browsing. It runs on most web browsers using a plug-in to function. We created a limited selection of avatars from which to choose that would be gender, race, profession, and attire specific. This significantly reduced start-up time allowed participants to choose a pre-configured avatar rather than customizing a new avatar. The interface is browser-based and has up-down mouse-look capability, keyboard movement control, and mouse-click interaction, with an option to call up menus and activate virtual objects.

The VR environment and presenting case scenarios were designed for a combination of three to four concurrent players: one provider (either a physician or advanced practice clinician), one nurse, one other clinician (another nurse or medical assistant), and one office staff member (a receptionist or any non-clinical support staff). Each scenario could be played multiple times by a mix of the same participants from one design cycle to the next. For example, they could perform the chest pain scenario

on iteration one, then replay it with designed improvements in iteration two, then also play the next case of an allergic reaction during iteration two, which was the first run of the allergic reaction case (see Figure 4 for the iterative cycles). New participants could engage in any iteration. Participants communicated via VOIP or by conducting the simulation using multiple laptops in the same room so that they could speak to and hear each other. On-site technical help was available due to the novel nature of the experience for the participants, but minimal assistance was required after a brief orientation to the avatar controls and environment.

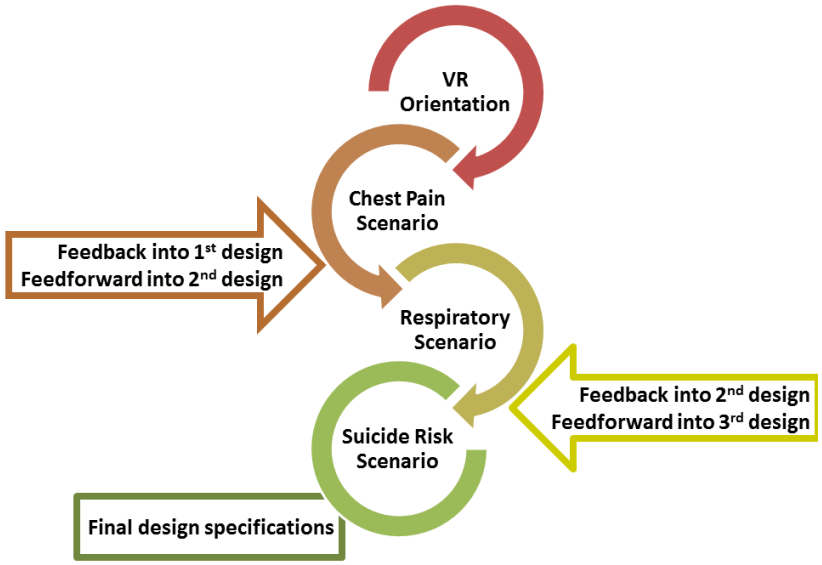


Figure 4. Iterative design cycles

Confederate actors played the patient, including the patient's voice, patient avatar movement, and turning on certain programmed scripts that would lead to particular avatar animations (grasping chest, gasping for air, or nervous agitation) and physiological data (pulse, blood pressure, and temperature). Voice changing technology was used so the patient actor could play both male and female roles. Instructors and researchers communicated via in-world text messaging, a feature that was turned off for the learners. Instructors were able to view the participants from a ceiling angle looking down and could review critical action logs that were also visible to the participants (see Figure 5). Orientation occurred via the experience of coming in-world to a specifically programmed starting point just outside the clinic, where a series of information boards were placed, which the learners could approach and read. Also, some of the virtual objects they would encounter (the emergency cart) were also situated in the orientation area to build familiarity. Orientation took approximately 15 minutes and included time for questions.

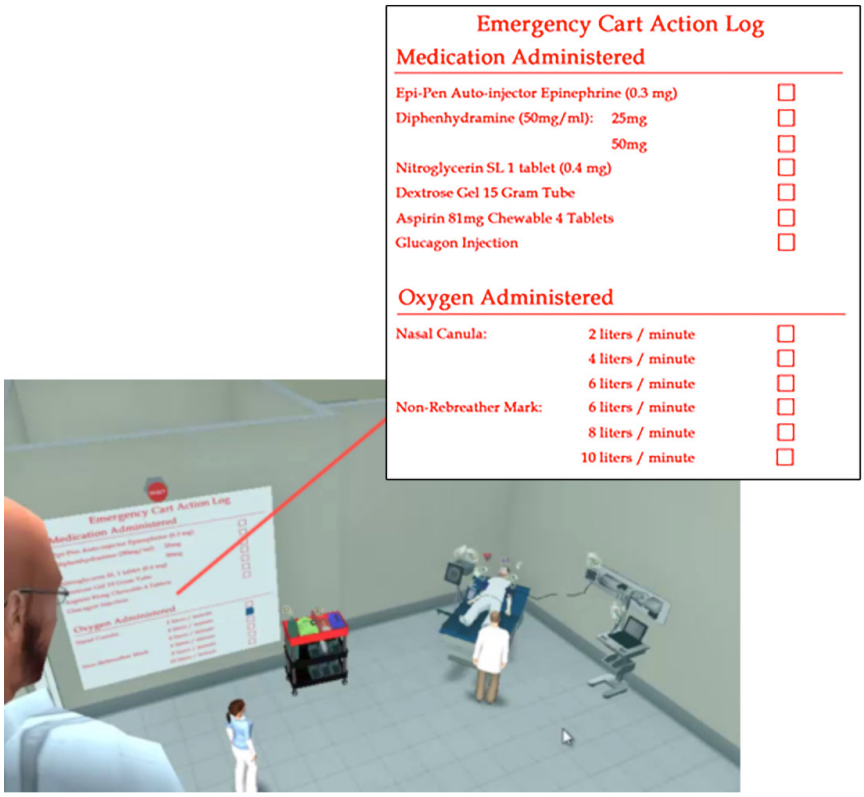


Figure 5. Critical action log visible to the participants during the simulation exercise

2.2 Data Collection and Analysis

Data were collected through a combination of in-world observations during the scenarios, in-world video recordings using Camtasia Studio, self-completion questionnaires, and semi-structured group interviews. Observations of the student-student, student-patient, and student-artifact(s) interactions in the virtual environment were captured by the in-world video log and observation notes. Performance data related to task completion were captured through observation checklists, qualitative observations, the learner-visible in world log, and the checklist used by the instructor. The post-activity survey covered participants' reactions and perceptions of the content objectives, overall design, navigation and interface, realism, authenticity, immersion, adoption, critical thinking, self-confidence, and inter-professionalism using a 4-point Likert scale (strongly agree, agree, disagree, or strongly disagree). A copy is provided in Table 3.

Table 3. Post-activity survey covered participants' reactions and perceptions

VR Office Based Medical Emergency
Post Activity Survey Tool

Demographics

Group ID	**5 different groups; 7 game plays**
Name	
Gender	**2 Male 16 Female**
Age	**0% <21 17% 21-30 22% 31-40 40% 41-50 17% 51-60 4% 60+**
Work email address	
Role/ credential	**11% Provider 11% RN 17% LPN 0% MAI 33% MAII 28% Clerical**
Location where you participated	
Have you played a computer game in the last year	**50% Yes**
Have you used a virtual environment before	**28% Yes**
Have you encountered an office based emergency before	**89% Yes:**

33% Asthma, 6% Anaphylaxis, 11% Other Respiratory, 17% Cardiac Arrest, 83% Chest Pain, 11% Other Cardiac, 0% Shock, 17% Seizure, 0% Other Neurologic, 11% Behavioral Health, 6% Other Not Listed: *Acute blood loss*

Content Objectives	**☐ Poor**	**☐ Fair**	**☐Good**	**☐Excellent**
Rate how well you think each of the following objectives were achieved in the VR:				
• Identify signs and symptoms that a patient is in distress.	-	-	**9**	**9**
• Identify and locate proper personnel and equipment.	**1**	-	**9**	**8**
• Provide appropriate treatment strategy to stabilize patient.	-	-	**10**	**8**

Overall Design	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**
1. I felt that the case was at the **appropriate level of difficulty** for my level of training.	-	-	**12**	**6**
2. The **group was the right size** to facilitate my learning.	-	-	**12**	**6**
3. Overall, working through this case was a **worthwhile** learning experience.	-	-	**11**	7

Navigation and Interface	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**
4. When I clicked on **objects they responded the way I expected.**	-	**1**	**16**	**1**
5. It was **easy to control** my avatar.	**1**	**2**	**15**	-
6. I was **able to find my way** around the office.	-	-	**14**	**4**

Realism	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**	
7. The office and clinical objects were **visually accurate.**	-	-	**13**	**5**	
8. The **patient animation was sufficient** to give clues as to what was going on.	-	-	**13**	**5**	
9. When the patient first displayed a problem it **felt real to me.**	-	**2**	**11**	**5**	
10. I was **able to get the patient's vital** signs.	-	-	**7**	**6**	**5 NA**
11. I was able to **find the medications** and select the correct dosages from the medications box on the cart.	-	-	**8**	**5**	**5 NA**

(continued)

Authenticity	Strongly ☐ Disagree	☐ Disagree	☐Agree	☐Strongly Agree	
12. The accuracy of the VR **kept my attention**.	-	-	**10**	**8**	
13. This case scenario **could really happen** in our office.	-	-	**6**	**12**	
14. I felt a **sense of the urgency** to help the patient.	-	**1**	**8**	**9**	
Immersion	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**	
15. It felt as if **I was actually in the situation**.	-	**2**	**13**	**3**	
16. I felt **my own anxiety increase** as the patient symptoms became more serious.	-	**5**	**9**	**4**	
17. I was **no longer paying attention** to what was going on around me.	**3**	**3**	**10**	**2**	
Adoption	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**	
18. I enjoyed the **game-like quality**.	-	-	**12**	**6**	
19. I would **recommend this activity to others**.	-	-	**10**	**8**	
20. I would **like to participate in more** virtual simulations.	-	**1**	**13**	**4**	
Critical Thinking	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**	
21. I have a **better understanding** of the use for our emergency medical cart.	-	-	**13**	**3**	**2 NA**
22. This **scenario has prepared me** to make better clinical decisions in the care of our patients.	-	**2**	**7**	**3**	**6 NA**
23. The simulation **clarified the priority of actions** needed for a patient in a similar situation.	-	**1**	**9**	**6**	**2 NA**
Self-Confidence	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**	
24. I have a better **appreciation for being prepared** for an office emergency.	-	**1**	**13**	**4**	
25. The VR simulation has **increased my self-confidence** about working in my office.	-	**3**	**13**	**2**	
26. I feel **more confident to react** to a medical emergency as a result of participating in this VR simulation.	-	**2**	**13**	**3**	
Interprofessionalism	**Strongly ☐ Disagree**	**☐ Disagree**	**☐Agree**	**☐Strongly Agree**	
27. The virtual representations of my team (other avatars) gave me a **greater sense of their presence**.	-	-	**15**	**3**	
28. I enjoyed **doing this activity as a team**.	-	-	**13**	**5**	
29. I think playing in the VR as a team will help me **communicate more effectively** in the office.	-	-	**15**	**3**	

Direct observations were conducted through in-world presence during the activity from a bird's-eye view above the office (refer to Figure 5). From the participants' view looking up, they saw opaque

ceiling tiles. From above looking down, however, the ceiling appeared transparent. Video data provided a means for the design team to objectively recall and review key segments and interactions to gain greater insight into the participants' experience. With these methods, researchers could observe the intended design compared with the participants' actual use in the social context of learning.

The debriefing was led by clinical faculty and a medical educator. These individuals were skilled in simulation-based education and had participated in prior faculty development workshops and/or created faculty development workshops on the topic of debriefing. A semi-structured approach was used to guide the debriefing discussion. It was intended to ensure topic areas relevant to the research were covered and to explore participants' reactions, feelings, and observations on timing, sequencing, relevance, and the scenario objectives related to their experience of the VR simulation. Debriefing was conducted either in person or remotely using VOIP, depending on faculty availability and location, immediately upon completion of a simulation case. The debriefing had two phases. First, a set of debriefing standard open-ended questions accompanied each case. Then, the debrief leader sought to identify major gaps in technical performance, process of care issues, or safety issues. These were addressed via the essential format of debriefing with good judgment described by Rudolph et al. (2007; 2014). The debriefing moved on to address issues of communication and teamwork as time allowed. Finally, the lead instructional designer debriefed the participants regarding their in-world experience, including communication, environmental, scenario, and other issues relevant to design. A post-activity questionnaire was delivered electronically using Qualtrics software to gather demographic information, including age, gender, professional licensure, rating of design features, and comments about the simulation, refer to Table 3. The questionnaire served as the transition from the virtual case scenario to the debriefing.

Data analysis was used to triangulate the data sources, methods, and investigators. NVivo software was used following a coding manual, and Excel software was used for descriptive statistics. This allowed for a robust analysis of the design in action, participants' experience, and knowledge and skill application.

2.3 Results

Using a design-based research approach, we created three office-based emergency scenarios (cardiac, respiratory, and behavioral health) in a virtual setting. Design-based research facilitated the small project team's quickly building expertise without accumulating unreasonable costs associated with experimental technology. With each design iteration, improvements were made to the virtual reality simulation process (orientation, case presentation, debriefing), the virtual environment (artifacts, interactions, options, and environmentally scripted feedback), and the scenarios themselves (sequencing, patient history, and patient responses). Having the participants as co-producers was invaluable to refining the instructional design framework. Feedback was coded into 14 nodes with the majority of feedback focused on five areas: audio and visual fidelity, authentic and believable content, object selection, manipulation and control, technical issues, and feedback mechanisms (see Table 4).

Table 4. The most frequently occurring design elements based on observation and participant feedback

Five Key Design Areas	Most Frequently Encountered Design Elements (Derived from participant comments and direct observations.)
Audio and Visual Fidelity	High degree of visual and audio accuracy Value control to enhance visuals and sounds
Authentic and Believable Content	Scenario narrative based on fact Content reflects appropriate cause and effect relationships Alignment with reality Provide clear overlap between the virtual activity and the target situation
Object Selection, Manipulation, and Control	Simple user interface Intuitive to navigate and exert control over the environment
Technical Issues	The VR environment and objects within it perform and behave as designed Exploit affordances of the technology to support the learning objectives
Feedback Mechanisms	Scaffolding of support to give clues Prompted feedback to cue next action Labeling of objects and use of mouse-over pop-up messages providing contextualized feedback Inclusion of a visually displayed action log that shows what critical actions were taken interacting with the emergency cart

Qualitative feedback confirmed that the more visually aligned the VR simulation was with their office setting, the greater the participants' comfort, curiosity, and willingness to participate. Our design and development efforts were limited to those elements that could be mapped back to particular learning objectives in the scenarios. Qualitative feedback suggested that too much detail was considered unnecessary and even distracting for the participants in some situations. For example, including visual representations of specific contents of closets, cupboards, draws and counter tops, participants began noticing inevitable variances from their particular office setting and were distracted from the critical incidents and actions making up the simulation activity.

3. Discussion

The identified five key design elements provide a valuable framework for developers to follow. Learners noted that the fidelity of virtual objects was important. However, learners also noted the importance of the fidelity of the entire VR scenario and not just specific objects that comprise it. The designer needs to be intentional about the overall composition, using visual effects to guide the participant without distorting reality to such a degree that it becomes distracting. 3D design needs to be concerned with the configuration of the VR, the sense of immersion perceived by the participants, and the authenticity of the narrative represented in the content. For example, the patient avatars needed to reflect skin pallor, body movement, animations, age, and height-weight ratio aligned to the presenting emergency. In two of the cases participants correctly identified the nature of emergency based on visual cues alone.

Authenticity, sequence, and alignment with reality are interrelated concepts. Authentic clinical content should have obvious value to the participants. The sequence of events must follow the expected cause and effect relationships shared from moment to moment. The participant's ability to accept the

scenario as believable encompasses the unified whole experienced by the participant and how he/she relates to it, moment by moment. There needs to be congruence among and between virtual objects and the overall virtual environment in which they appear.

The overall experience of the VR is mediated by the user interface, which should be considered carefully. Also, the virtual environment context that mediates interaction can impact the learning. For example, clicking on the ECG machine to see the ECG is intuitive and valuable. The intuitiveness of the interface seemed to contribute more to participants' continued performance and engagement in the VR than the number of successive experiences the participant has. Even with an intuitive interface, our participants valued a meaningful orientation. The orientation worked best when it involved relevant content as well as variability to encourage curiosity and self-discovery of objects and their function in the VR. We believe our orientation was successful because it allowed the discovery of objects and their function within the VR. For example, the introduction of the virtual emergency cart during orientation allowed the participants to explore how to trigger and deliver medications. Part of the participants' orientation should include feedback that is triggered based on the actions they take in the VR because they expect automated feedback within the VR experience. The VR platform allows for scripts that provide cues or responses to the participants' actions. These feedback mechanisms contribute to the experience of cause and effect in the VR. In this research, feedback mechanisms were used to give clues and cues to take action, navigate, manipulate, and demonstrate control of the environment.

3.1 Use of Design Aids

Using a template for scenario design with customizations for the virtual environment was helpful and echoes the usefulness of templates in manikin-based simulations. We found that videotaping followed by storyboarding of the proposed scenarios helped the digital asset developers who did not understand the process of care from the back office perspective and engaged the clinicians in the technical design. These aids helped us move from learning objectives to effective simulation and then share the educational needs for avatar animations, artifacts, and interactions. The feedback from participants was extremely helpful early on, with diminishing returns as the simulations improved. Faculty felt it was extremely beneficial to be able to observe scenarios from the ceiling view. Other platforms have accomplished faculty viewing by using invisible avatars (Clinispace), and others attempt to automate all feedback and remove the faculty from the process (Anesoft, Standardpatient.org, and others). Those efforts will only improve as natural language processing and artificial intelligence behind both the avatars and the in-world assessments become more refined.

3.2 Leveraging Technology

Initially, our project had approval for operation behind the network firewall. The plan involved all users accessing the platform via a browser on their usual desktop computer connected to the corporate network, which is also connected to our clinical information systems. However, midway through the development of our project, a software upgrade to the AvayaLive Engage platform enabled desktop and file sharing capabilities. Despite reassurances that we would not be using this feature, fears about clinical data security risks led our information services to block access to the platform website. Thus, we moved the research onto non-network laptops using external hotspots. This was functional but negated many of the benefits of using the virtual environment remotely due to set-up requirements. Future virtual reality education projects would do well to investigate fully security features of any proposed platforms and consider in-network installation options.

The development of this project took place in the AvayaLive Engage virtual environment platform, which we selected for its rich feature set, low-end client system requirements, simple user interface, and ability to create customized environments. The custom clinical environment was created using a combination of multimedia content creation packages as well as a modified version of the Unreal Engine 2.5, which is provided to subscribers of the AvayaLive Engage platform.

It should be noted that our team had limited prior experience with these particular VR development tools. The AvayaLive

Engage documentation and online community resources were helpful to learn the core features, but learning to push the engine beyond the provided functionality proved challenging due to the fact that the Unreal Engine 2.5 was no longer in widespread use. In order to supplement our own efforts and keep the project on track, we outsourced to an external developer custom 3D animations of the patient avatars such as the rubbing of the chest in the chest pain scenario and the grasping of chest and gasping for air in the allergic reaction scenario.

3.3 How to Begin

The development process began with several onsite visits to the medical office, where we collected photographic and video references of the real-world outpatient setting. During this process, we paid particularly close attention to the layout of the environment, the equipment found in each patient room; the textures found on the floors, walls, and ceiling; and how the office staff interacted with their environment and clinical artifacts within the environment.

The overall layout of the environment and construction of the outpatient setting was created using the Unreal Engine's internal BSP brush tools. A floor plan of the real-world outpatient environment was used as a blueprint to construct the virtual environment layout. In order to decrease any sense of claustrophobia and provide a degree of forgiveness to users unfamiliar with navigating an avatar in a 3D environment, the virtual outpatient setting was scaled up by a factor of roughly 2.5 times that of the real outpatient building.

All of the 3D objects populating the environment were created using Autodesk Maya and textured using Photoshop. Due to the nature of the browser-based virtual environment, it was recommended to keep the file-size of the entire environment under 25MB for an easier download. With this in mind, we made sure to utilize efficient low-polygon geometry modeling techniques and conservative texture sizes in order to capture the essence of the objects without pushing the boundaries of file-size reasonability. Similarly, in cases where multiple instances of an object were required in the environment, it was more efficient to duplicate and reposition the same 3D model than it was to create unique instances for each.

3.4 Limitations

This research was limited due to the size of our test audience, and the resulting design may reflect our local health system context. Within this development phase, we did not conduct a final assessment of the learners' ability to apply the knowledge, skills, and abilities imparted in the VR training. Future efforts could follow virtual training with an assessment by methods such as in situ simulation. The design-based approach to research blurs the distinction between learners and designers and could bias the participants in favor of the technology and design. The iterative design makes the overall evaluation less useful to others than it was to the original designers.

4. Conclusion

Novel outpatient emergency scenarios in a first-person-perspective virtual environment were successfully created. This research provided practical insights into the design of virtual reality simulations for clinicians to respond to infrequently occurring emergency events. Using a design-based approach allowed the research team and the participants to collaboratively effect incremental changes during development, observe results, and anchor on an optimal design. Pilot testing revealed successful rapid development, implementation, and participant orientation, with the ability to present meaningful learning opportunities.

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