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Featured Article

Designing a Virtual Simulation Game as Presimulation Preparation for a Respiratory Distress Simulation for Senior Nursing Students: Usability, Feasibility, and Perceived Impact on Learning

Marian Luctkar-Flude, RN PhD, CCSNE[a,*], Jane Tyerman, RN PhD, CCSNE[b], Deborah Tregunno, RN, PhD[a], Caitlin Bell, RN, BNSc, BAH[a], Michelle Lalonde, RN, PhD[b], Tammie McParland, RN, PhD, CCSNE[c], Laurie Peachey, RN, PhD, CCSNE[c], Margaret Verkuyl, NP-PHC, MN[d], Paula Mastrilli, RN, PhD[e]

[a]*Queen's University, School of Nursing, Kingston, Ontario, Canada*
[b]*University of Ottawa, School of Nursing, Ottawa, Ontario, Canada*
[c]*Nipissing University, School of Nursing, North Bay, Ontario, Canada*
[d]*Centennial College, Nursing Programs, Toronto, Ontario, Canada*
[e]*George Brown College, Simulation Centre, Toronto, Ontario, Canada*

KEYWORDS
virtual simulation;
simulation game;
presimulation preparation;
usability testing

Abstract

Background: We designed a virtual simulation game (VSG) as presimulation preparation for a respiratory distress simulation for undergraduate nursing students.

Method: Three faculty members and three nursing students were observed playing the VSG, provided written feedback, and completed a usability survey. After implementation, learners ($n = 92$) completed the ClassRoom Instructional Support Perception scale for case study or VSG.

Results: Participants indicated that the VSG was easy to use (83.3%), fun (83.3%), useful to prepare students for simulation (83.3%), and rated higher than case study for usability ($p = .011$), engagement ($p = .005$), and learning ($p = .021$).

Conclusion: Presimulation preparation with VSG was feasible, and highly rated by nursing students.

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[*] Corresponding author: mfl1@queensu.ca (M. Luctkar-Flude).

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Traditional learning approaches in nursing education are being replaced by active learner-centered experiential approaches such as clinical simulation (Jeffries & Clochesy, 2012). Presimulation preparation is a critical aspect of simulation-based learning; however, learners often do not complete traditional presimulation activities such as assigned readings and may not be adequately prepared to actively participate in simulation (Tyerman, Luctkar-Flude, Graham, Coffey, & Olsen-Lynch, 2019). In an effort to better engage nursing students, prepare them for simulation, and enhance their learning, we developed a virtual simulation game (VSG) as presimulation preparation for a deteriorating patient scenario focused on the management of a patient experiencing respiratory distress due to a pulmonary embolus. In this article, we describe the process and results of usability testing before and after implementation of the VSG within a critical care nursing course for senior nursing students.

Key Points

- Nurse educators can easily create their own virtual simulation games (VSGs).
- It is feasible to use a brief VSG as preparation for in-person simulations.
- Nursing students rated the VSGs highly in terms of usability, engagement, and learning.

Background

The variation in clinical placements assigned to nursing students allows for a varied exposure to specific clinical situations, which can cause missed opportunities to experience certain conditions as not all have the same practical experiences before graduation (McKenna et al., 2014). Recently, students studying in urban centers in Canada had a distinct decline in access to specialty areas in acute care clinical placements (Niederhauser, Schoessler, Gubrud-Howe, Magnussen, & Codier, 2012; Poikela, Ruokamo, & Teras, 2015). Nursing students and postgraduate nurses may have low clinical confidence despite adequate knowledge, which leads to poor performance in complex emergency situations (Cooper et al., 2015, Curran, Fleet, & Greene, 2012; Endacott, Cooper, Sheaff, Padmore, & Blakely, 2010). To prepare for professional practice, there needs to be an improvement in the provision of a stimulating and safe learning environment for student nurses to practice clinical skills and applications of knowledge and clinical decision-making. Well-designed simulation-based education in nursing contributes to better knowledge, skills, confidence, communication, and critical thinking (Cant & Cooper, 2010, 2017; Schubert, 2012). Students have access to a broader range of situations that may not occur during their clinical placements through the use of simulation laboratories, thereby learning to respond to unfamiliar and emergency situations. Students are able to assess the effect their decisions have on patient care without needing to be anxious about inflicting patient harm (Fisher & King, 2013 Lewis & Veale, 2010; Linnard-Palmer, Phillips, Fink, Catolico, & Sweeny, 2012). Using high-fidelity patient simulations as a teaching and learning strategy has resulted in a marked improvement in nurses' response to clinical emergency situations (Buckley & Gordon, 2011); (Buykx et al., 2011).

There are three distinct phases of the simulation experience: preparation, participation, and debriefing (Husebo, Friberg, Soreide, & Rystedt, 2012; (Luctkar-Flude, 2020); Oermann & Gaberson, 2018). Although the presimulation preparation phase has not been well-studied, it is a critical phase, which involves applying material in advance of the scenario to optimize learning (Tyerman et al., 2019). In our experience with traditional presimulation activities, students may prepare ineffectively for simulation. Activities included in traditional presimulation include textbook readings, lectures, and quizzes. Learners can close the gap between desired and actual performance using assessment rubrics outlining learning outcomes and descriptors (Ellery, 2008). In a recent study, senior nursing students perceived that integration of learning outcomes assessment rubrics enhanced their self-regulated learning and presimulation preparation (Luctkar-Flude, Tregunno, Egan, Sears, & Tyerman, 2019). Virtual games and other alternate presimulation preparation activities may improve learning outcomes according to results of a systemic review of the literature (Tyerman et al., 2019).

Virtual gaming simulations are games accessed by computer for the purpose of education or training rather than entertainment (Verkuyl, Atack, Mastrilli, & Romaniuk, 2016). Virtual games can be used as supplemental alongside classroom and simulation laboratory learning (Cant & Cooper, 2014). Along with being a simulation of real-world scenarios, the user feels motivated to succeed by being immersed in the game, using the gaming feature of identity, as they act as a character in the given scenario (Annetta, 2010). After playing virtual games designed to develop pediatric skills, nursing students reported high satisfaction and immersion (Verkuyl et al., 2017). Virtual games pique interest, encourage thinking, and require active participation, all of which stimulate motivation and learning (Garris, Ahlers, & Driskell, 2002). VSGs allow the opportunity to engage in clinical decision-making situations that are unavailable to nursing students in their own clinical practice. The learner is typically given immediate feedback and has the opportunity to repeat the game until they are satisfied with their performance. Simulations, including virtual experiences, allow the participant to feel how it is to be a professional in action (Berragan, 2011).

We proposed that a short VSG based on learning outcomes could both engage learners and help them to prepare to participate in a full-length live clinical simulation in the simulation laboratory. The purpose of our study was to evaluate the usability and feasibility of this approach as well as to evaluate the perceived impact on learning. Evaluation of usability and selection of measurement tools was guided by the Technology Acceptance Model (Davis, 1989), which describes the concepts of perceived ease of use (the degree to which a person believes using a technology will be free of effort) and perceived usefulness (the extent to which a person believes using a technology will enhance their performance). Both concepts are indicators of an individual's motivation to use a particular technology, an important consideration when designing technology-based educational interventions such as VSGs.

Methods

As part of a multisite randomized controlled trial, we developed a VSG to prepare learners to participate in a live respiratory distress simulation as part of a critical care nursing course. The study was approved by the university's Health Sciences Research Ethics Board, and informed consent was obtained from all participants. Three stages of usability testing were undertaken. Each stage used different measures as the purpose of each stage was different. Stage 1 focused on ensuring content was accurate and flowed logically. Stage 2 focused on identifying technical issues with the game, and Stage 3 focused on the overall user experience.

Stage 1: VSG Development and Review

A video-based VSG was developed focused on management of a patient with respiratory distress from a pulmonary embolus. The VSG included five decision points based on the learning outcomes for the simulation. Nursing faculty on the research team was invited to review the VSG and provide feedback on the game design, the game flow, the decision points, the rationale behind the decisions, and issues with the technology. This feedback was then related directly to the expert game designer and incorporated into the game before formal usability testing.

Stage 2: Usability Testing With Sample of Nursing Faculty and Students

Using convenience sampling, students along with nursing faculty were invited to test the game and provide feedback throughout the game play, as well as after the game was terminated. A sample of six participants was recruited. Most problems related to usability usually reveal themselves after four participants are tested; as such, usability studies typically involve five to seven participants (Rubin, Chisnell, & Spool, 2008). Participants were observed by one of the researchers through game play and were asked for their opinions throughout. The participants' progressions through the game as well as their comments were recorded using the Virtual Simulation Game Usability Checklist (VSG-UC), an adaptation of a checklist that was used previously for the evaluation of VSGs (Verkuyl et al., 2016).

On completion of the game, the participants completed a 14-item usability survey, the Virtual Simulation Game Technology Acceptance Survey (VSG-TAS), which is used to evaluate the ease of use and usefulness of the game. The survey used a five-point Likert scale ranging from strongly disagree to strongly agree. The VSG-TAS is based on the Technology Acceptance Model (Davis, 1989), and used in a previous study in a customized format to evaluate VSGs (Verkuyl et al., 2016). Evidence for the validity and reliability of the survey items and subscales have previously been reported (Atack, Gignac, & Anderson, 2010). As we report the results of this survey descriptively, we did not perform a psychometric analysis in our study.

Following the VSG Usability Testing Interview Guide, researchers garnered more elaborate feedback by completing a brief semistructured interview, which allowed participants to discuss any problems they faced and provide recommendations for improvements. This interview guide has been previously used in the evaluation of VSGs and was adapted to fit our study (Verkuyl et al., 2016). Notes were taken by the researchers in lieu of recording the interviews.

Stage 3: Post-VSG Implementation Usability Survey

An additional postsimulation usability survey was given to study participants recruited for the larger implementation and evaluation study. Results of the multisite evaluation study, which measured cost utility, anxiety, self-confidence, and learning outcomes, will be published elsewhere. Usability testing took place at one of the four participating sites. Usability survey participants were fourth year BNSc nursing students (n = 92) enrolled in a critical care nursing course. The three nursing students who participated in the stage 2 usability testing did not participate in the stage 3 implementation study usability survey to avoid potential bias. Participants were randomized to prepare for an in-person simulation using either a case study (CS) or the VSG. The CS questions completed by the control group aligned directly with the five decision points included in the VSG. The in-person simulation was an expanded version of the VSG scenario and CS content. The usability survey was distributed at one of the four participating sites where the respiratory distress VSG was developed. The survey is the ClassRoom Instructional Support Perception scale (CRISP), which is an adaptation of the CRISP survey used previously to evaluate classroom response systems (Richardson, Dunn, McDonald, & Oprescu, 2015). This validated 12-item survey has three subscales, which measure learner perceptions of the usability, engagement, and impact on learning of a given educational intervention (Sheng, Goldie, Pulling, & Luctkar-Flude, 2019). Each item is rated from 1 (strongly disagree) to 5 (strongly agree). With permission from the scale developers, scale items were modified to evaluate the usability of the CS and the VSG. Learners in the control group completed the CRISP-CS and those in the experimental group completed the CRISP-VSG. Sample items from the three subscales are as follows: (1) usability: for me it was easy to use the VSG/CS; (2) engagement: using the VSG/CS has increased my enjoyment of learning; and (3) impact on learning: using the VSG/CS allowed me to better understand key concepts.

Data Analysis

Quantitative survey data were analyzed using descriptive statistics using SPSS version 21 (IBM Corp, Armonk, NY). Frequencies and percentages were reported to describe Likert scale responses to the usability testing stage survey, whereas independent samples t-tests were calculated to compare subscale scores for the implementation stage usability survey. Cronbach's alpha was calculated for the three CRISP subscales to provide preliminary evidence of reliability when used to measure usability components of VSGs and case studies as instructional strategies. The primary investigator at the site observed participants in the usability testing stage. Qualitative feedback is grouped thematically and described narratively.

Results

Research team members reviewed each game and provided feedback to the game developer and incorporated into the VSG before usability testing.

Usability Testing

Formal usability testing was conducted with a sample of three nursing students and three nursing faculty members. Five participants were female and one male. The mean age of the participants was 28.2 years. Video game experience varied widely among the participants. Of the participants, 50% reported never playing video games, 50% reported occasionally playing video games, and 0% reported frequently playing video games. There was an even divide between participants who had participated in a video simulation game experience and those who had not. One participant (16.7%) had never played a video simulation game experience, whereas four participants (66.7%) had played 1 to 2 games and one (16.7%) had played 3 to 4 games previously.

During usability testing, most users were able to commence the game with minimal prompting and follow through the flow of the game without needing clarifications from researchers. These reviewers reported that the game was easy to learn (83.3%), easy to know what to do (83.3%), with no technological problems reported (83.3%) (see Table 1). Most reviewers indicated scores of agree to strongly agree to all the survey items except for two: reviewers did not agree that the game "helped communicate using therapeutic principles" and "helped collaborate with team members." Game play time ranged between approximately 10 and 17 minutes.

Overall, the reviewer responses to the VSG Usability Testing Interview questions were positive. They reported that the beginning of the game clearly outlined the instructions and purpose of the game as there was "sufficient information provided to initiate the game". One reviewer suggested a trial round initially to familiarize

Table 1 Usability Testing: Virtual Simulation Game Technology Acceptance Survey Results

Survey Item	Frequency (%)
Easy to learn	
Strongly disagree	1 (16.7%)
Agree	3 (50.0%)
Strongly agree	2 (33.3%)
Text on screen was clear	
Strongly disagree	1 (16.7%)
Agree	2 (33.3%)
Strongly agree	3 (50.0%)
Text on screen was easy to read	
Strongly disagree	1 (16.7%)
Agree	2 (33.3%)
Strongly agree	3 (50.0%)
Easy to know what to do	
Strongly disagree	1 (16.7%)
Agree	2 (33.3%)
Strongly agree	3 (50.0%)
No technological problems	
Strongly disagree	1 (16.7%)
Agree	2 (33.3%)
Strongly agree	3 (50.0%)
Good visual quality	
Strongly disagree	1 (16.7%)
Agree	2 (33.3%)
Strongly agree	3 (50.0%)
Fun to use	
Strongly disagree	1 (16.7%)
Agree	3 (50.0%)
Strongly agree	2 (33.3%)
Good pace	
Strongly disagree	1 (16.7%)
Agree	3 (50.0%)
Strongly agree	2 (33.3%)
Good audio quality	
Strongly disagree	1 (16.7%)
Agree	3 (50.0%)
Strongly agree	2 (33.3%)
Helped prepare for live simulations	1 (16.7%)
Strongly disagree	2 (33.3%)
Agree	3 (50.0%)
Strongly agree	
Helped communicate critical changes in health status	
Strongly disagree	1 (16.7%)
Disagree	1 (16.7%)
Agree	2 (33.3%)
Strongly agree	2 (33.3%)
Helped perform critical measures for deteriorating patient	
Strongly disagree	1 (16.7%)
Neutral	1 (16.7%)
Agree	1 (16.7%)
Strongly agree	3 (50.0%)
Helped communicate using therapeutic principles	

(*continued on next page*)

Table 1 (*continued*)

Survey Item	Frequency (%)
Strongly disagree	1 (16.7%)
Neutral	2 (33.3%)
Agree	2 (33.3%)
Strongly agree	1 (16.7%)
Helped collaborate with team members	
Strongly disagree	1 (16.7%)
Disagree	1 (16.7%)
Neutral	2 (33.3%)
Agree	2 (33.3%)

participants with a VSG but overall reported the game to be "very easy, simple, and straight forward."

Occasionally throughout the game, there would be lengthy videos preceding a decision point, which was reported by users to hinder their decision-making processes. Some reviewers suggested having more frequent decision points to lessen the length of video portions. Because this VSG was part of a larger study, we were not able to increase the number of decision points; however, we were able to take this feedback into consideration when developing further VSGs.

After a decision point, there was an option to click a link to bring up a pop up of the rationale for the correct decision; however, the rationale was not automatically provided otherwise. Some users found they were not visually drawn to the link and at times "forgot to click on it" because "the button did not stand out." However, reviewers reported mainly positive feedback regarding the provision of rationale as it "highlights critical thinking components that students should demonstrate" and "guides students through the nursing thought process." The recommendation from some reviewers was "for the rationale box to automatically open after selecting the response." Changes were made to the VSG before the larger implementation study incorporating this feedback.

Implementation Study Usability Survey

A total of 92 fourth year BNSc nursing students participated in the implementation study and completed the usability survey. Results of the CRISP implementation surveys demonstrated that learners rated the VSG as easier to use ($p = .011$), more engaging ($p = .005$), and contributing more to their learning ($p = .021$) than a comparable CS (see Table 2). The three subscales of the CRISP survey demonstrated good reliability as demonstrated by Cronbach's alphas of 0.795 (usability), 0.888 (engagement), and 0.824 (learning).

Learners were also encouraged to provide qualitative feedback about the VSG. Responses were overwhelmingly positive and fell under five themes: engagement, presimulation preparation, rationale, time, and learning (see Table 3). These responses supported that the VSG was "easy to use" and "interactive, relevant, and engaging." Other learners commented on the use of the VSG for presimulation preparation, for example, that the VSG provided "better preparation for sim lab, allowed me to choose interventions and obtain immediate feedback on my decisions," "it was nice to do a mock assessment before going into the lab," "I felt more prepared and less anxious." Many learners identified the rationale provided as a helpful aspect of the game, for example, "I liked that it provided options and rationale for decision making." In addition, learners pointed out several ways that the VSG supported their learning. One learner stated, "I'm a visual learner and it really helped me focus and learn," and another said, "makes you think critically about what you would do." In terms of improving the VSG, a couple of learners suggested that it could have been longer "it could have had more responses to select and go into more detail, I really liked it but it was quick," and "wish it was longer."

Discussion

This study set out to determine users ease of use, perceived usefulness, engagement, and impact on learning of a newly developed VSG designed to be used as a presimulation preparation for a respiratory distress simulation. The participants found the VSG to be an engaging, interactive, and relevant way to prepare for an in-person simulation. These characteristics are an important aspect to consider as there are no reports on the degree students complete assigned preparatory work (Tyerman et al., 2019) but what is known is preparation builds confidence and competence in students to engage in in-person simulation and

Table 2 Learner Implementation Usability Surveys: CRISP-VSG Results

	Mean (SD)				
CRISP Subscales	Control Group (Case Study) N = 48	Experimental Group (VSG) N = 44	t-test	Sig (2-Tailed)	Effect size (Cohen's d)
Usability (4 items: Score/20)	15.54 (2.44)	17.05 (3.06)	−2.592	.011	0.546
Engagement (9 items: Score/45)	33.41 (4.69)	36.30 (5.25)	−2.849	.005	0.520
Learning (12 items: Score/60)	43.64 (5.99)	46.61 (5.68)	−2.357	.021	0.509

Note. CRISP = ClassRoom Instructional Support Perception; SD = standard deviation; VSG = virtual simulation game.

Table 3 Qualitative Feedback About VLEs by Theme and Category

	Debriefing	Relevance to Learner	Degree of Realism	Engagement	Categorical Design Quality
Static Print	"Talking through the case studies and being asked questions was really helpful in putting everything together in clinical." (L1) "The success in learning through this format relies heavily on the instructor." (L2) "Got to discuss, then in a collaborative way rather than individualistic which was nice." (L2)	"Helpful to understand the full picture of a patient in the hospital" (L2) "Did not help us interact with patients" (L2) "Level 1 [students] would benefit… [from this activity] to get used to answering questions about documenting, but after that I don't think it adds to our knowledge or practice" (L3)	"This option gave us lots of in-depth critical thinking practice that you don't always get in actually hospital clinical" (L4)	"Felt like busy work" (L1) "It seems to be more of a hassle than anything." (L3) "Redundant. A lot of re-typing what was in the above paragraph" (L4)	"I liked that I was able to take my time and look up additional information." (L1) "It was good just very time consuming." (L2) "Took me HOURS to complete and by the end I was totally disengaged and didn't even care to fill them out to the best of my ability" (L4)
Static Audio	No specific comments on post discussion VLE in this category	"Felt very relevant." (L1) "Good activity for perspective; had no impact on learning material for exams" (L3)	"Left an impression that I really took care of a patient from the time he was admitted, to after his discharge." (L1) "Provided insight into what patients experience" (L3)	"Podcasts create an imagery for me. I rather enjoyed this one." (L1) "I really enjoyed this one." (L1)	"Didn't find it challenging enough" (L3) "…very memorable and unique… won't forget this" (L3)
Interactive Web	No specific comments on post discussion VLE in this category	"It was a really seemingly silly activity, but it actually did contribute to a lot of learning for me. I was genuinely surprised how memorable it was" (L1) "Would be better in my opinion as a refresher at the beginning of level 2 or 3 as an optional exercise." (L4)	"They should add this game to semester 1 before starting clinical to get an idea of how careful we have to be when giving medications" (L1) "It felt like being in the clinical setting. Being able to complete tasks while there is chaos around you can prove to build a strong-minded nurse." (L4)	"I enjoyed the interactive, engaging portion of this format." (L1) "Would like even more options" (L1) "This program was fun while also a great teaching tool." (LM) "The format kept my interest. It just took some time to understand the process." (L4)	"This [activity] had a few errors and the instructions were not clear on some of the games." (L1) "This was my favorite virtual clinical activity. It was interactive and helpful." (LM) "It was incredibly frustrating to be asked to [...] learn another program haphazard format during the final days of our semester." (L4)
Static Video	"Discussions in clinical made this a great success" (L1) "I enjoyed online clinical for assignments and critical thinking to discuss one case in detail." (L3)	"Some…expanded on concepts, but most just seemed to be additional information. This was beneficial but not necessarily always relevant." (L2) "Videos were helpful, but some of the material and skills shown or covered in the videos weren't in line with what we have been taught…" (L2) "Good way to engage what we learn in theory and how we would put it in practice." (L2)	"These videos were helpful to see how a nurse should/should not act in many situations." (L1) "That is as close to clinicals and real-life experience as you can get." (L3)	"Allowed me to watch several times to understand the concepts" (L2) "I loved them so much that I ended up watching all of the videos just for more knowledge!" (L2)	"The video was poorly done and so weird it was distracting. It actually made it more difficult to concentrate on what I was supposed to be learning." (L1) "The videos where we could see nursing behaviors and how they interacted with patients was very valuable in demonstrating the "good" and "not so good" behaviors." (L1)
Interactive Video/ Sim	"The discussions in clinical were insightful and illuminating." (L2)	"I think these activities were beneficial but did not always seem to pertain specifically to the material that we were covering in lectures." (L2) "I enjoyed seeing what we learn in theory and what it looks like with a real patient. It brings everything together." (L2) "Utilized exactly what was in lecture!" (L4)	"Made me feel like a nurse" (L3) "Makes you feel like you're putting an actual shift in." (L3) "Felt pretty intense and allowed us to feel what an emergency might feel/look like" (L4)	"This activity was engaging, interesting and when I was done, I felt like I really learned a lot." (L4) "Very fun and engaging, I wish there was more scenarios." (L4)	"I appreciated the thought and details that went into this." (L4) "They're well made, slick to work with, and modern." (L4)

L1 = Level 1 student; L2 = Level 2 student; L3 = Level 3 student; L4 = Level 4 student; LM = mobility (accelerated) student.

decreases performance anxiety (Gantt, 2013). Our participants also felt they were less anxious and more prepared for their in-person simulation.

In-person simulation opportunities are increasing in nursing education with some programs replacing up to 50% clinical with simulation (Hayden, Smiley, Alexander, Kardong-Edgren, & Jeffries, 2014). But, in-person simulation is costly and faculty intensive; therefore, optimizing the learning is crucial. One way to do this is through effective presimulation preparation activities. A review by Tyerman et al. (2019) found improved knowledge, self-confidence, clinical judgment and performance, and lowered anxiety with presimulation preparation activities. Creating effective presimulation VSGs could be the answer to optimizing learning through in-person simulations.

Overall, participants at each stage of usability testing found the VSG to be easy to use. One usability tester with no previous video game experience found the experience more challenging than those with any video game experience but was still able to successfully navigate the study VSG. There were a few comments made by the participants that the developers were able to resolve. For example, the rationale button did not stand out, so the button was removed, and now the rationale screen pops up automatically after the selection of either a correct or incorrect response. Some of the videos were longer in length (over one minute) than other video clips, which slows the pace of the game. No changes can be made to the current game, but in future projects the development team will try to keep the videos down to less than one minute, with the exception of the introductory scene that sets the stage for the VSG.

After usability testing, the VSG was implemented within a critical care nursing course as part of a larger study to evaluate the cost-utility and learning outcomes associated with using VSGs for presimulation preparation. Implementation of this study demonstrated the feasibility of using the VSGs to prepare nursing students to participate in face-to-face simulations. Results of the implementation survey demonstrated that learners rated the VSG as easier to use, more engaging, and contributing more to their learning than a CS.

The VSG was designed to meet course learning objectives including: ‘‘communicate using therapeutic principles’’ and ‘‘collaboration with team members.’’ Most usability testing participants did not agree that the game contributed to meeting these particular objectives. This may be due to the restriction of five decision points per presimulation preparation game that limited opportunities to demonstrate these competencies. It was anticipated that participation in the face-to-face simulation after completing the VSG would enhance achieving these competencies. Further evaluation after the live simulations is indicated to determine whether these outcomes were met or whether changes to the VSG are required. Recently, a graduate student used the same VSG design process to create a presimulation preparation activity for senior nursing students to better prepare them to participate in cardiac resuscitation rounds, which are composed of live simulations focused on applications of Basic Life Support and Advanced Cardiac Life Support skills (Keys, Luctkar-Flude, Tyerman, Sears, & Woo, 2020). Evaluation of this VSG, which focused specifically on a ventricular fibrillation (v-fib) arrest, was conducted using a pilot randomized controlled trial. Results are pending publication and will add to our knowledge of impact of using VSGs as presimulation preparation.

Using technology to develop new ways of learning is important in nursing education, especially for digital native students. Our study supports other studies that found visual and interactive aspect of the VSG helped students focus and learn when compared to traditional learning (Miller & Jensen, 2014; Ulrich, Farra, Smith, & Hodgson, 2014; Verkuyl & Hughes, 2019). As in-person simulation is such an interactive, experiential experience, a natural progression is to create presimulation activities with the same characteristics.

Conclusion

A usability test was conducted to assess the facility and ease of use of a VSG to be applied in a critical care course for senior baccalaureate nursing students. The VSG was rated highly by educators and students in terms of usability, engagement, and learning. In addition, learners rated presimulation preparation with a VSG significantly higher than with a CS. With minor adjustments provided through usability testing, the VSG will be used as presimulation preparation for a live simulation scenario focused on respiratory distress. We anticipate that the VSG will be an engaging presimulation preparation activity that could contribute to the promotion of self-regulated learning, enhanced knowledge, decreased anxiety, and enhanced preparation and performance during a live simulation scenario. Further study is needed to determine best practices and learner outcomes associated with using VSGs for presimulation preparation, and potentially as a replacement for some live simulations.

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Development and Implementation of Augmented Reality Enhanced High-Fidelity Simulation for Recognition of Patient Decompensation

Matthew W. Zackoff, MD, MEd; Bradley Cruse, MFA; Rashmi D. Sahay, MD, MS; Lin Fei, PhD; Jennifer Saupe, MSN, RN-BC, CNS; Jerome Schwartz, MHHA, RN, NE-BC; Melissa Klein, MD, MEd; Gary L. Geis, MD; Ken Tegtmeyer, MD

Introduction: Simulation is a core aspect of training and assessment; however, simulation laboratories are limited in their ability to visually represent mental, respiratory, and perfusion status. Augmented reality (AR) represents a potential adjunct to address this gap.

Methods: A prospective, observational pilot of interprofessional simulation assessing a decompensating patient was conducted from April to June 2019. Teams completed 2 simulations: (1) traditional training (TT) using a manikin (Laerdal SimJunior) and (2) AR-enhanced training (ART) using a manikin plus an AR patient. The primary outcome was self-assessed effectiveness at the assessment of patient decompensation. Secondary outcomes were attitudes toward and adverse effects during the AR training.

Results: Twenty-one simulation sessions included 84 participants in headsets. Participants reported improved ability to assess the patient's mental status, respiratory status, and perfusion status (all P < 0.0001) during ART in comparison to TT. Similar findings were noted for recognition of hypoxemia, shock, apnea, and decompensation (all P≤ 0.0003) but not for recognition of cardiac arrest (P = 0.06). Most participants agreed or strongly agreed that ART accurately depicted a decompensating patient (89%), reinforced key components of the patient assessment (88%), and will impact how they care for patients (68%). Augmented reality–enhanced training was rated more effective than manikin training and standardized patients and equally as effective as bedside teaching.

Conclusions: This novel application of AR to enhance the realism of manikin simulation demonstrated improvement in self-assessed recognition of patient decompensation. Augmented reality may represent a viable modality for increasing the clinical impact of training. (Sim Healthcare 16:221–230, 2021)

Key Words: Simulation-based medical education, augmented reality, decompensation, cardiopulmonary arrest.

Simulation[1] has become a core aspect of medical training and assessment. Implementation of simulation ranges from task trainers[1] to interprofessional sessions using manikins[1] within comprehensive simulation laboratories. The degree of realism[1] or authenticity presented within simulation thus ranges along a spectrum from completely artificial to an actual real-life situation. In addition, the level of fidelity[1] offered needs to be appropriate to the task(s) required and providers' level of training, ie, more advanced trainees or providers require higher-fidelity simulation to support practice of a task.[2]

From the Department of Pediatrics (M.W.Z., R.D.S., L.F., M.K., G.L.G., K.T.), University of Cincinnati College of Medicine; and Division of Critical Care Medicine (M.W.Z., K.T.), Center for Simulation and Research (B.C.), Division of Biostatistics and Epidemiology (R. D.S., L.F.), Center for Professional Excellence (J.Sa., J.Sc.), and Divisions of General and Community Pediatrics (M.K.) and Emergency Medicine (G.L.G.), Cincinnati Children's Hospital Medical Center, Cincinnati, OH.

Correspondence to: Matthew W. Zackoff, MD, MEd, Cincinnati Children's Hospital Medical Center, 3333 Burnet Ave, MLC 2005, Cincinnati, OH 45229 (e-mail: matthew. zackoff@cchmc.org).

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Through advancing technology, simulation educators have replicated clinical situations with the integration of vital sign data and manikins that respond to learners' actions.[3–10] However, even the most advanced manikins and simulation scenarios require the learner to suspend their disbelief because of manikins being visibly different from actual patients (ie, inability to display mental status, respiratory dysfunction, or perfusion abnormalities).[3,5,8,11]

Although each generation of manikin has improved in realism (ie, blinking, pupillary changes, cyanosis), these systems come with considerable cost. Inroads have been made with screen-based simulation[1] through virtual scenarios using a computer interface to replicate real-life cases[12–14]; however, the interaction with the program/software has usually been limited to one learner, whereas clinical care in code situations requires interprofessional teams. To date, there has been limited attempt to bridge the divide and incorporate virtual tools to enhance the realism and immersion of widely available simulation mannequins either in the training laboratory or in situ simulation settings for clinical training for multiple learners.[15,16]

The emerging technologies of virtual reality (VR) and augmented reality (AR) represent potential adjuncts to current simulation training.[1,3,17] To address the specific gap related to interprofessional code team training, we created an AR patient—a realistic virtual representation of a patient that is projected into the field of view of the learner. Unlike VR, which places the user in a completely virtual environment, AR provides the benefit of inclusion of virtual content while still allowing for visualization and interaction with the other participants, equipment, and resources present in the real-life environment. By limiting our virtual content to an AR overlay of the computerized manikin, we hoped to gain the benefits of a more realistic patient while leveraging the available functionality of the manikin and simulation laboratory.

The objectives of our work were to develop an AR overlay for a commercially available manikin, embed that overlay within a simulation-based code team training curriculum, and perform a pilot study to explore the feasibility and acceptability of the AR overlay as compared with manikin training alone.

METHODS

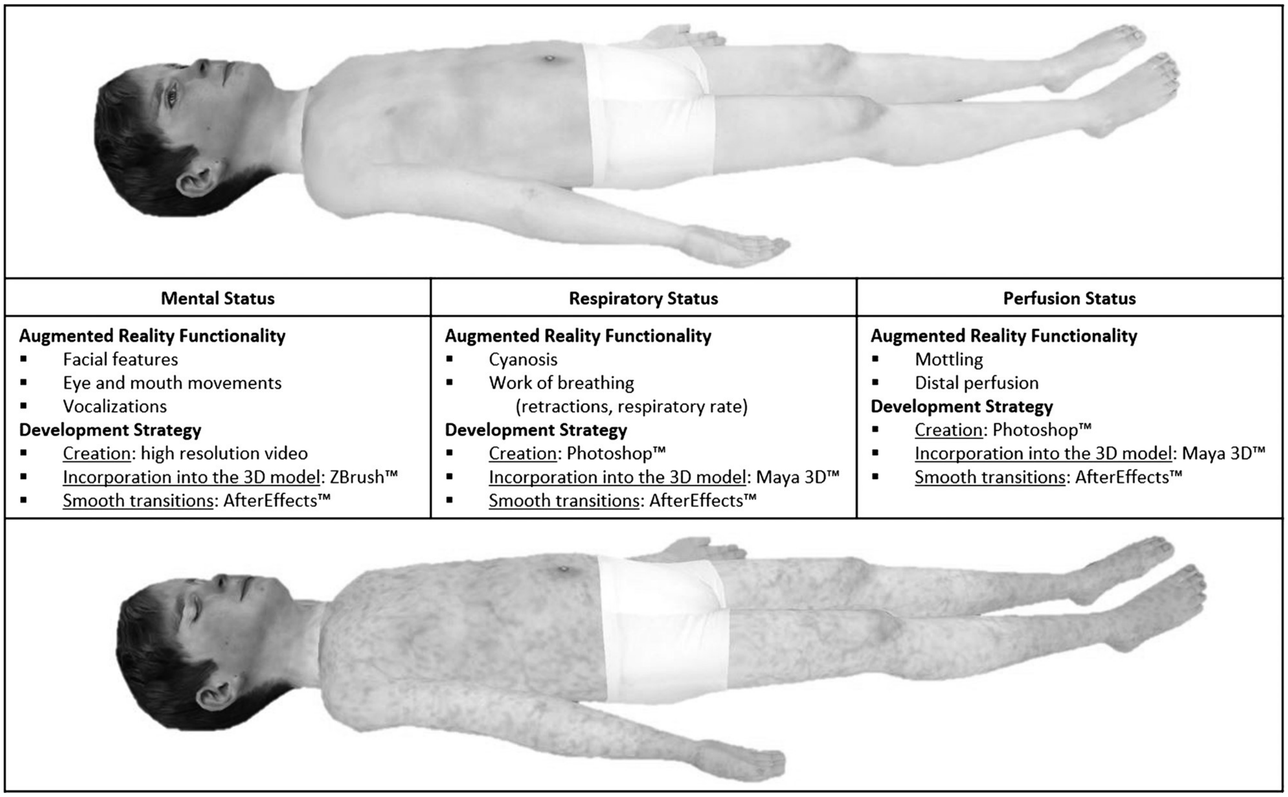
The process of developing and exploring the feasibility and acceptability of an AR overlay for a manikin simulation (assessing and managing a pediatric patient as he progresses from compensated shock, to decompensated shock, to an arrest state, and back to compensated shock) included the following steps.

Phase 1: Development of the AR Patient

The goal of the AR enhancement was to facilitate the presentation of key patient findings (mental, respiratory, and perfusion status) that are either difficult or impossible to simulate with current widely available manikins. Although some new manikins can present additional key findings such as eye movements, pupillary changes, and cyanosis through colored lights, manikins available at many simulation centers remain limited. To that end, an AR patient that could be used as an overlay for commonly available manikins was developed as a collaboration between physicians, medical animators, and programmers, with the key functionality and development strategy outlined in Figure 1. The dimensions of the AR patient were made to match the dimensions of the SimJunior manikin from Laerdal (Stavanger, Norway; Fig. 2), which was the manikin used for this study.

Our digital animation team modeled and unwrapped the manikin from high-resolution photos using Maya 3D modeling and animation software. Skin changes (ie, mottling, poor distal perfusion, cyanosis) were created by editing the unwrapped manikin's texture maps in Photoshop, a graphics editing software. To increase the realism related to the patient's mental status, high-resolution video footage of a volunteer actor was used for the facial features, eye and mouth movements, and vocalizations. These video frames were projection painted onto the 3-dimensional model of the manikin's head using the program ZBrush, with the animations layered (ie, smooth transitions between facial expressions) using AfterEffects, a video processing software. A similar layering approach allowed for smooth transitions through progressive skin changes (mottling, distal ischemia) and work of breathing (intercostal retractions, abdominal breathing). All content was then structured within the Unity platform, a virtual environment software and game engine.

Three patient presentations were developed that corresponded to changes in clinical status during the simulation scenario. Each presentation included a description of the patient's clinical status with specific visual and auditory findings for mental status (eye opening/closing, verbalizations, and responsiveness), respiratory status (oxygen saturation, cyanosis, work of breathing, and respiratory rate), and perfusion status (degree of



Mental Status	Respiratory Status	Perfusion Status
Augmented Reality Functionality ▪ Facial features ▪ Eye and mouth movements ▪ Vocalizations **Development Strategy** ▪ Creation: high resolution video ▪ Incorporation into the 3D model: ZBrush™ ▪ Smooth transitions: AfterEffects™	**Augmented Reality Functionality** ▪ Cyanosis ▪ Work of breathing (retractions, respiratory rate) **Development Strategy** ▪ Creation: Photoshop™ ▪ Incorporation into the 3D model: Maya 3D™ ▪ Smooth transitions: AfterEffects™	**Augmented Reality Functionality** ▪ Mottling ▪ Distal perfusion **Development Strategy** ▪ Creation: Photoshop™ ▪ Incorporation into the 3D model: Maya 3D™ ▪ Smooth transitions: AfterEffects™

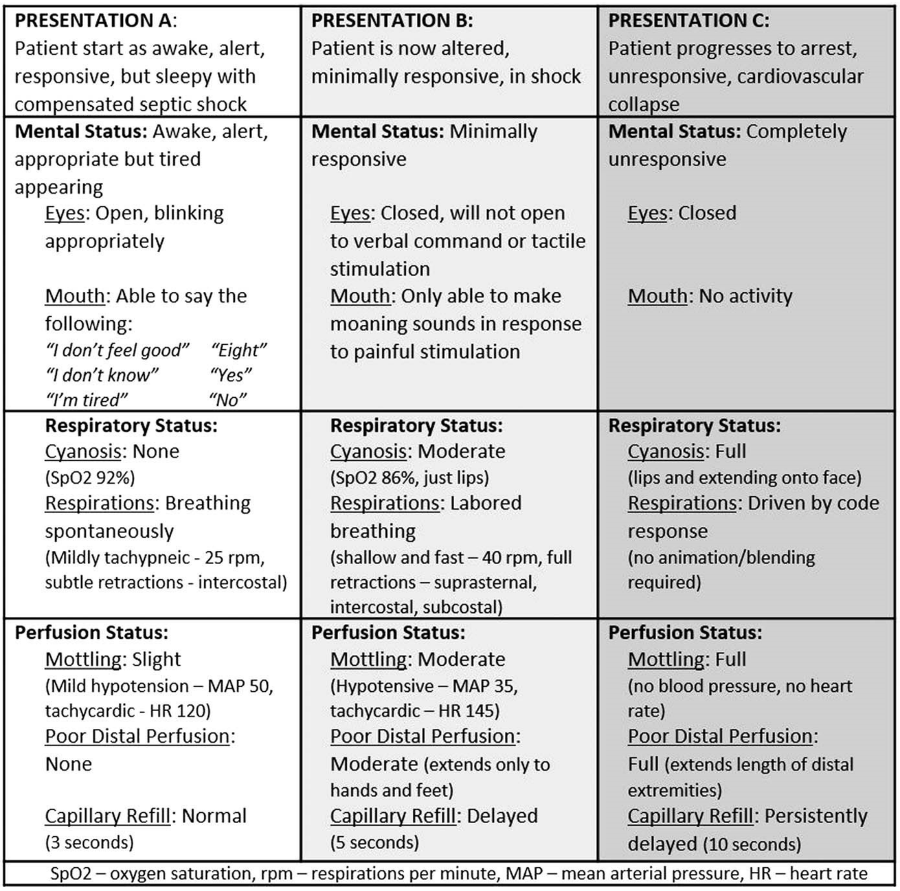
FIGURE 1. Augmented reality functionality for the key assessment components (mental, respiratory, and perfusion status) and used development strategy.

FIGURE 2. The AR patient, consisting of high-resolution animations and video footage, was designed to match the dimensions of the manikin being used in the simulation scenarios to allow a smooth overlay during the simulation.

mottling and distal extremity ischemia, heart rate, and blood pressure; Fig. 3).

Phase 2: Integration Into the Manikin Scenario

To integrate the AR patient into the manikin simulation, we chose an interface that allowed free mobility and concurrent use by multiple participants. We leveraged Apple's ARKit 2, a platform for imbedding virtual content, to create an application for (1) accessing the AR patient, (2) overlaying and anchoring the AR patient through object recognition of the manikin using the platforms object scanning functionality, and (3) remotely changing the clinical presentation of the AR patient for all users in real time as the scenario progressed. The application embedded the AR patient into the simulation while allowing unimpeded visualization of the rest of the real-world environment. This approach leveraged the fidelity benefits of the simulation laboratory and avoided recreating in VR all of the equipment, monitors, and personnel required



PRESENTATION A: Patient start as awake, alert, responsive, but sleepy with compensated septic shock	**PRESENTATION B:** Patient is now altered, minimally responsive, in shock	**PRESENTATION C:** Patient progresses to arrest, unresponsive, cardiovascular collapse
Mental Status: Awake, alert, appropriate but tired appearing <u>Eyes</u>: Open, blinking appropriately <u>Mouth</u>: Able to say the following: *"I don't feel good"* *"Eight"* *"I don't know"* *"Yes"* *"I'm tired"* *"No"*	**Mental Status:** Minimally responsive <u>Eyes</u>: Closed, will not open to verbal command or tactile stimulation <u>Mouth</u>: Only able to make moaning sounds in response to painful stimulation	**Mental Status:** Completely unresponsive <u>Eyes</u>: Closed <u>Mouth</u>: No activity
Respiratory Status: <u>Cyanosis</u>: None (SpO2 92%) <u>Respirations</u>: Breathing spontaneously (Mildly tachypneic - 25 rpm, subtle retractions - intercostal)	**Respiratory Status:** <u>Cyanosis</u>: Moderate (SpO2 86%, just lips) <u>Respirations</u>: Labored breathing (shallow and fast – 40 rpm, full retractions – suprasternal, intercostal, subcostal)	**Respiratory Status:** <u>Cyanosis</u>: Full (lips and extending onto face) <u>Respirations</u>: Driven by code response (no animation/blending required)
Perfusion Status: <u>Mottling</u>: Slight (Mild hypotension – MAP 50, tachycardic - HR 120) <u>Poor Distal Perfusion</u>: None <u>Capillary Refill</u>: Normal (3 seconds)	**Perfusion Status:** <u>Mottling</u>: Moderate (Hypotensive – MAP 35, tachycardic – HR 145) <u>Poor Distal Perfusion</u>: Moderate (extends only to hands and feet) <u>Capillary Refill</u>: Delayed (5 seconds)	**Perfusion Status:** <u>Mottling</u>: Full (no blood pressure, no heart rate) <u>Poor Distal Perfusion</u>: Full (extends length of distal extremities) <u>Capillary Refill</u>: Persistently delayed (10 seconds)
SpO2 – oxygen saturation, rpm – respirations per minute, MAP – mean arterial pressure, HR – heart rate		

FIGURE3. The 3 developed patient presentations represented by the AR patient and aligning with the vital signs displayed by the manikin.

when providing clinical care for a decompensating patient. Lastly, the entire program was compiled and published for use on Apple devices via XCode.

The iPhone XS was used as the interface for participants for several reasons. In addition to running Apple's ARKit 2, the phone was suspended in a lightweight headset, facilitating hands-free use for visualizing the participant's environment. The AR patient's clinical findings were adjusted via the controller interface on a Wi-Fi linked iPad, networked via Photon Engine. The use of iPhones and iPads created a cord-free experience, allowing for safer and more realistic navigation of the simulation laboratory during the scenario. This platform was selected over other commercially available headsets because of the clarity of the image, whereas other available platforms' images were difficult to visualize in the well-lit code environment and had too restrictive a field of view. Having all of the devices communicate over Wi-Fi allowed the facilitator controlling the AR patient to operate remotely within the simulation room and allowed for streamlined communication with the technician controlling the manikin and linked vital sign monitor. All clinical findings and actions were controlled via a simple interface incorporating check boxes and sliders.

Phase 3: AR-Enhanced Manikin Simulation Piloting

The simulation scenario was developed by interprofessional clinicians with expertise in critical care, emergency medicine, education, and simulation. The scenario was designed to incorporate the key assessment and management steps required in the care of a decompensating patient— allowing for a representative scenario to test the functionality of the AR enhancement. Formalized goals and objectives and a scenario flowchart were created to standardize the experience (Appendix 1). The interprofessional teams completed 2 scenarios during the simulation session, a traditional training (TT) simulation using a manikin in the simulation laboratory, followed by an AR-enhanced training (ART) simulation using a manikin plus the AR patient in the same setting. This structure was selected to allow a uniform basis for comparison in that all participants would have a standardized manikin simulation for comparison to the AR-enhanced simulation.

During the ART simulation, headsets were worn by the provider lead, nurse lead, bedside nurse, and respiratory therapist (see Video, Supplemental Digital Content 1, available at http://links.lww.com/SIH/A549, which shows a session with participants in headsets and a view of the virtual patient and control interface). The 2-scenario session was piloted first with 2 groups of simulation educators to address session logistical hurdles and to identify any safety hazards of navigating the simulation laboratory while in the AR headset. The simulation was further piloted on 3 groups of clinical personnel from the emergency department (ED). The ED groups were chosen as (a) they were not part of the intended study sample population and (b) they perform the designated roles of the simulation experience in actual clinical practice (ie, manage decompensating patients and respond to code scenarios).

Phase 4: Implementation of the AR-Enhanced Manikin Simulation

Setting and Study Population

A prospective, observational study to evaluate learner response to simulated decompensating patients was conducted at a large academic children's hospital from April to June 2019. Simulation sessions occurred in a simulation laboratory. Participants were recruited from the pediatric intensive care unit and cardiac intensive care unit to accurately reflect the composition of our institution's interprofessional care teams that manage decompensating patients and respond to code scenarios. The role of team lead was filled by critical care attending physicians, fellow physicians, or advanced practice nurses. The roles of nurse lead, bedside nurse, respiratory therapist, code cart nurse, and chest compression provider were filled by a representative sample of nurses and respiratory therapists from the pediatric intensive care unit and cardiac intensive care unit.

Although participation was considered part of routine team training, all participants were able to "opt out" of the study portions of the training at any time, and performance in all components would have no bearing on their job evaluations.

This study was approved by our institutional review board.

Outcomes and Measures

The primary outcome was self-assessed effectiveness at the assessment of patient decompensation. Secondary outcomes were attitudes toward and adverse effects experienced during the ART. Demographic and experience data were collected for all participants. For participants who wore the AR headset, we explored the feasibility and acceptability of AR through surveys assessing impact of AR on self-reported recognition of markers of patient decompensation, degree of immersion and adverse effects experienced during the AR simulation, and attitudes toward AR as an education modality.

The de novo survey evaluating effectiveness at identifying patient decompensation used a retrospective pre-post 5-point Likert scale to compare TT and the ART to actual clinical care. This survey methodology was selected to reduce response shift bias, in which learners may change their self-assessment standards over time as they encounter new concepts. This methodology attempts to mitigate overestimation or underestimation of abilities before experiencing the AR simulation.[18] Questions related to immersion and an inventory of potential adverse effects experienced while wearing the AR headset was also completed.[19,20] Lastly, tools previously used by the investigators were adapted to explore attitudes toward the AR simulation and compare it to traditional education modalities (Appendix 2).[21,22] Surveys were completed immediately following the simulation scenarios using a

TABLE 1. Demographic Data for the Participants Who Wore the AR Headsets

Demographics	All Participants (N = 84)	Physicians and Advanced Practice Nurses (n = 21)	Nurses (n = 42)	Respiratory Therapists (n = 21)	P*
Age, n (%), yr					0.01
20–24	4 (4.8)	0 (0)	3 (7.1)	1 (4.8)	
25–29	26 (31)	1 (4.8)	17 (40.5)	8 (38.1)	
30–34	22 (26.2)	9 (42.9)	9 (21.4)	4 (19.1)	
35–39	15 (17.9)	2 (9.5)	9 (21.4)	4 (19.1)	
>40	17 (20.2)	9 (42.9)	4 (9.5)	4 (19.1)	
Sex, n (%)					0.02
Male	22 (26.2)	10 (47.6)	6 (14.3)	6 (28.6)	
Female	62 (73.8)	11 (52.4)	36 (85.7)	15 (71.4)	
Race, n (%)					0.64
White or Caucasian	75 (89.3)	18 (85.7)	37 (88.1)	20 (95.2)	
Black or African American	1 (1.2)	0 (0)	0 (0)	1 (4.8)	
Asian	2 (2.4)	1 (4.8)	1 (2.4)	0 (0)	
Hispanic or Latino	1 (1.2)	0 (0)	1 (2.4)	0 (0)	
Other	5 (6)	2 (9.5)	3 (7.1)	0 (0)	
Experience in current role, n (%), yr				0.12	
<1	10 (11.9)	4 (19.1)	6 (14.3)	0 (0)	
1–2	4 (4.8)	3 (14.3)	0 (0)	1 (4.8)	
2–3	13 (15.5)	3 (14.3)	5 (11.9)	5 (23.8)	
3–5	18 (21.4)	3 (14.3)	11 (26.2)	4 (19.1)	
>5	39 (46.4)	8 (38.1)	20 (47.6)	11 (52.4)	

*Examining providers, nurses, and respiratory therapists using χ^2 or Fisher test.

secure web-based application (Research Electronic Data Capture—REDCap) facilitating deidentification and coding.[23] Semistructured debriefings after the simulation sessions were conducted by the primary investigator addressing the learning objectives of the simulation scenario and to gather additional feedback on the ART.

Statistical Analysis

All demographic data were summarized as frequencies and percentages for all participants and by participants' role. Group differences were examined using χ^2 or Fisher test as applicable. The Van Elteran test was used to compare ordinal responses between the ART and the TT scenarios, controlling for participants role. Summary statistics for all other outcomes were provided as counts and percentages. All statistical analyses were done as 2-sided tests with $P \leq 0.05$ deemed statistically significant, using SAS 9.4. Copyright (c) 2016 by SAS Institute, Inc, Cary, NC.

RESULTS

Demographics

Twenty-one separate simulation sessions were completed during the study period for a total of 132 unique participants. Eighty-four participants wore the AR headsets in the roles of provider lead, nurse lead, bedside nurse, and respiratory therapist. Demographic data are presented in Table 1.

Self-assessment of Effectiveness

Participants who wore the headsets reported significant differences in their ability to recognize key findings associated with patient decompensation when comparing ART and TT to actual clinical care (Table 2). Specifically, participants described a significant improvement in their ability to effectively assess the patient's mental status, respiratory status, and perfusion status during ART as compared with TT (all $P < 0.0001$). Similar findings were noted for recognition of hypoxemia requiring supplemental oxygen, shock requiring fluids, apnea requiring bagging, and decompensation requiring all interventions (all $P \leq 0.0003$). Only recognition of cardiac arrest and need for cardiopulmonary resuscitation did not significantly differ ($P = 0.06$) between the 2 scenarios.

Immersion and Adverse Effects

Most participants who wore the headsets agreed or strongly agreed that they devoted their whole attention to the virtual experience (n = 77, 91.6%) and that the virtual experience captured their senses (n = 71, 84.5%). A few participants agreed or strongly agreed that they could effectively be active in the environment of the simulation (n = 56, 66.6%). A few participants agreed or strongly agreed that they could effectively move among the objects in the simulation (n = 26, 31%) or gave them the impression that they could do things with the objects in the simulation (n = 37, 44.1%).

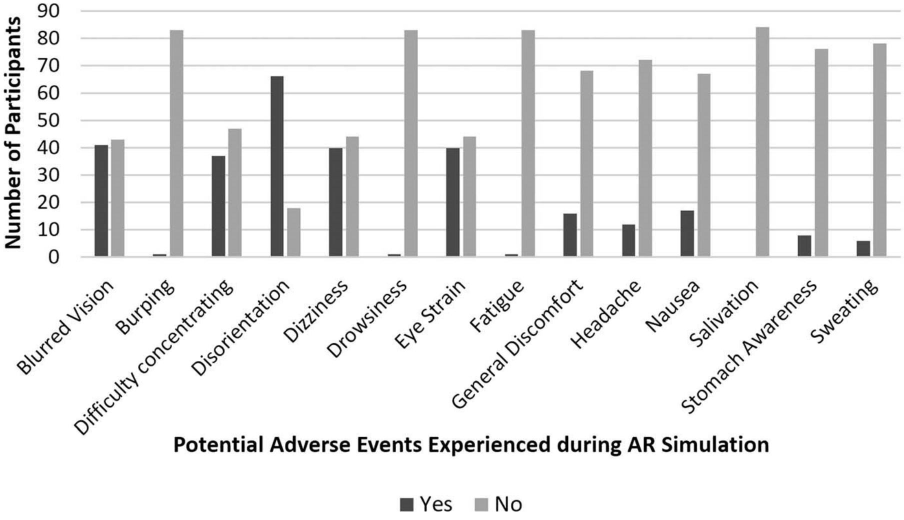
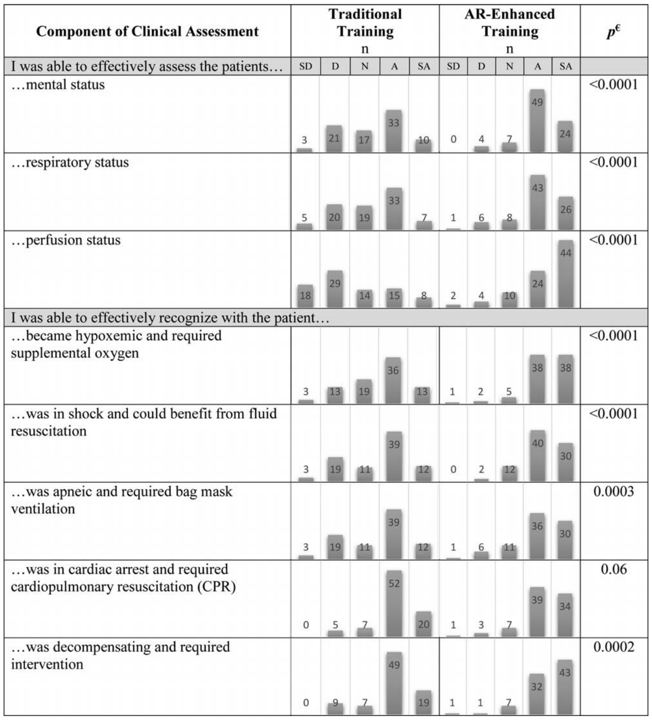


FIGURE 4. Participant reported adverse effects while wearing the AR headset.

TABLE 2. Examining Participant's Ability to Effectively Assess Key Components of Clinical Decompensation for the ART as Compared With Traditional Computerized Mannequin-Based Simulation Training



Component of Clinical Assessment	Traditional Training n					AR-Enhanced Training n					$p^{€}$
I was able to effectively assess the patients…	SD	D	N	A	SA	SD	D	N	A	SA	
…mental status	3	21	17	33	10	0	4	7	49	24	<0.0001
…respiratory status	5	20	19	33	7	1	6	8	43	26	<0.0001
…perfusion status	18	29	14	15	8	2	4	10	24	44	<0.0001
I was able to effectively recognize with the patient…											
…became hypoxemic and required supplemental oxygen	3	13	19	36	13	1	2	5	38	38	<0.0001
…was in shock and could benefit from fluid resuscitation	3	19	11	39	12	0	2	12	40	30	<0.0001
…was apneic and required bag mask ventilation	3	19	11	39	12	1	6	11	36	30	0.0003
…was in cardiac arrest and required cardiopulmonary resuscitation (CPR)	0	5	7	52	20	1	3	7	39	34	0.06
…was decompensating and required intervention	0	9	7	49	19	1	1	7	32	43	0.0002

*P from Van Elteren test.

A, agree; D, disagree; N, neutral; SD, strongly disagree; SA, strongly agree.

Participants who wore the headsets reported a variety of adverse effects. The only symptom experienced by most participants was disorientation (n = 66, 78.6%). Additional frequently experienced symptoms included blurred vision (n = 41, 48.8%), difficulty concentrating (n = 37, 44.1%), dizziness (n = 40, 47.6%), and eye strain (n = 40, 47.6%; Fig. 4).

Attitudes Toward AR Education

Most participants agreed or strongly agreed that the ART accurately depicted a decompensating patient (89%), reinforced key pieces of the assessment of a decompensating patient (88%), and will impact future assessment and response to decompensating patients (68%). Augmented reality education was additionally rated as more effective than reading, didactic teaching, online learning, low-fidelity manikins, standardized patients, and high-fidelity manikins. Bedside teaching was rated as equally effective to AR (Fig. 5).

DISCUSSION

This study represents one of the first applications of AR for clinical training in an effort to increase realism beyond what is provided by commonly available manikin simulators.[14–16] The incorporation of multiple AR headset users within interprofessional resuscitation training is also novel. Participants rated their ability to effectively identify and respond to a decompensating patient as significantly greater during ART as compared with TT. In addition, participants rated ART as superior in perceived effectiveness to other training options such as standardized patients and manikin-based simulation, while being equally effective as bedside teaching.

The ability of AR to accurately replicate key examination findings, such as mental status, respiratory distress, and perfusion changes, allowed for the addition of previously inaccessible clinical assessment data into the simulation. The resulting simulation experience, as measured in the participants wearing headsets, more accurately reflected actual practice. The ability of our AR-enhanced simulation to replicate key clinical findings may allow for more accurate assessment of clinical performance and provide a modality for more robust training on assessment of a patient's mental, respiratory, and perfusion status.

Importantly, to evaluate the applicability of this AR strategy for future simulations, it is necessary to consider the adverse events reported by the participants. The incidence of several symptoms, such as disorientation, dizziness, and blurred vision, was significant—representing a current limitation of the use of AR while performing clinical tasks. These findings, leveraged with the participant reports that most symptoms occurred when navigating the simulation environment and resolved when focusing on the AR patient, will help inform future applications of AR and guide the focus of ongoing development efforts around improving the AR interface.

This technical report and pilot study have several limitations. First, it was performed at a single site, with participants skewing toward a younger age, which may limit generalizability. However, our study used interprofessional care teams with participants performing the role they fill during actual clinical care, likely similar to team structure at other institutions. Second, the ordering of scenarios was static with every team experiencing ART simulation second to allow for consistent comparison to TT. It is possible that the participants were biased toward AR enhancement because of its novelty, performance improvement after experiencing the scenario traditionally, and/or the proximity of the ART to survey completion. In addition, we did not formally establish the participants' prior exposure to AR, which may have biased their perspectives. The incorporation of nonclinical cue AR components into both control and intervention training experiences (ie, room decor, family members, etc) could limit the potential AR novelty bias in future studies. Third, enrollment was limited to individuals who work in intensive care settings and have experience with simulation, and thus, AR enhancement may not demonstrate similar effects for other learners. However, less experienced providers may benefit more from this type of training through its ability to highlight examination findings that precede overt signs of deterioration. Fourth, only the participants who wore the headsets completed the comparative survey. We do not know how the addition of AR impacted the other (nonheadset wearing) participants. Fifth, outcome measures were limited to the Kirkpatrick level 2 or "learning level,"[24] with assessment for improvement in skills, behaviors, or patient care outside the scope of this pilot study. Given our use of novel technology required a significant time and financial investment, we felt that our chosen outcomes would best guide future work. Lastly, the development of our AR patient required animation and programming expertise. Although these skill sets are becoming more readily available, we recognize that these types of resources may not be currently available at many institutions. In an attempt to help offset costs for potential adopters at other institutions, we used less expensive and more readily available equipment, that is, iPads and iPhones.

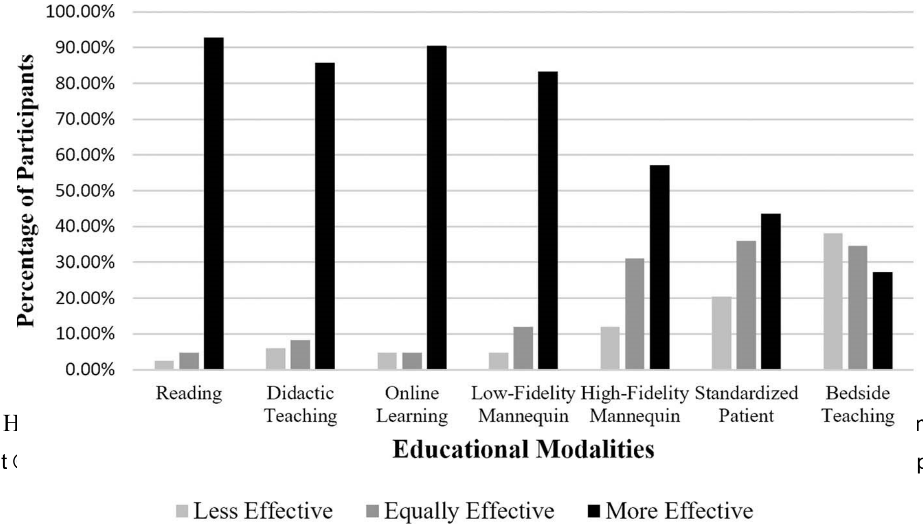


FIGURE 5. Participant assessment of effectiveness of AR training compared with other educational modalities.

Despite these limitations, we believe that the enhanced fidelity offered by AR and the positive response from participants suggest that AR may be a viable modality for enhancing the realism and fidelity of currently used manikins in many simulation centers and may help improve clinical assessment training. Further study will be focused on the direct comparison of ART to TT with regard to actual clinical performance metrics, such as time to cue recognition and task completion, as well as impact on retention and future performance in both simulated and nonsimulated clinical care.

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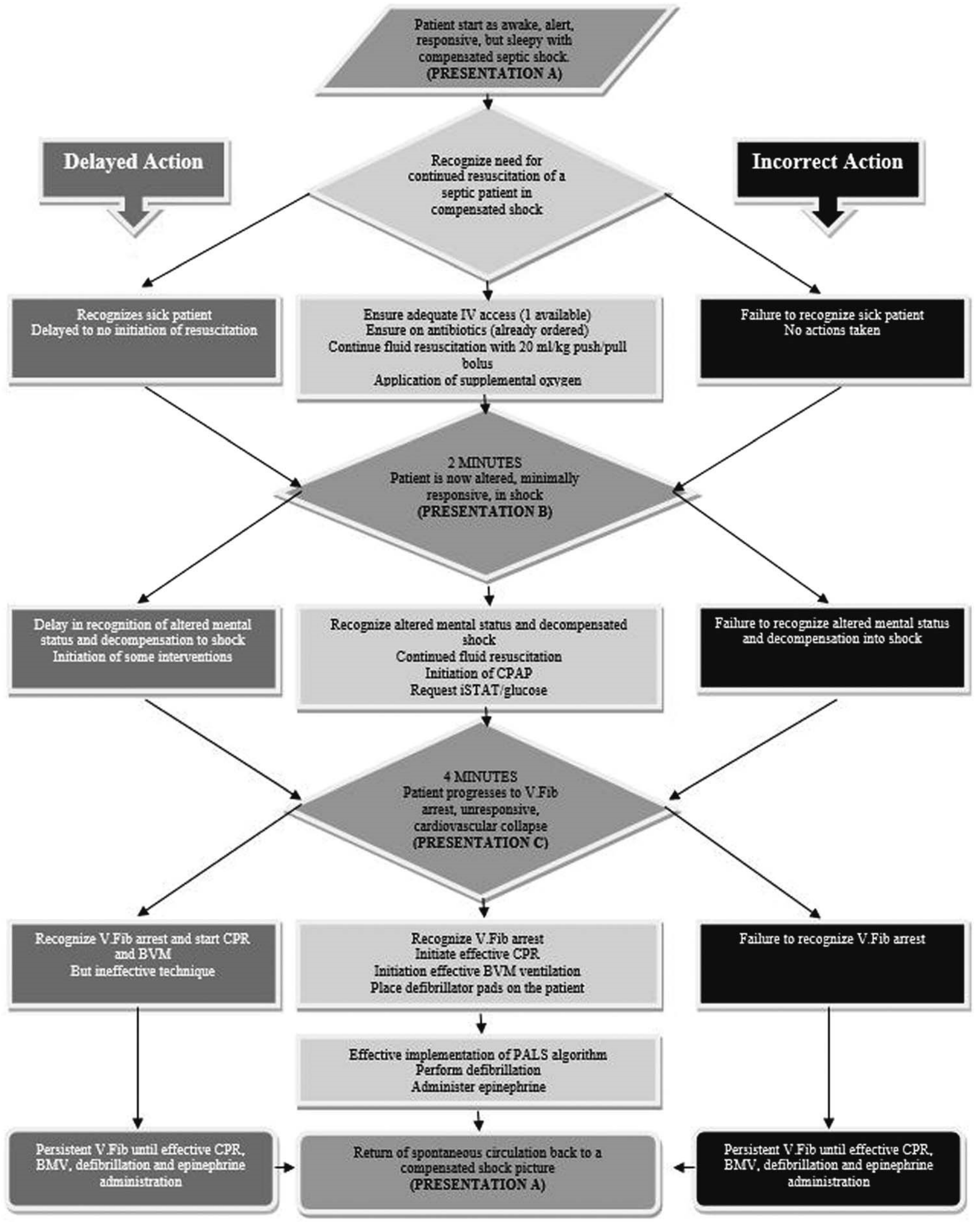
Appendix I:



Appendix II: Education Modality Attitudes

Augmented reality is one type of educational experience. Please answer the following questions about how augmented reality compares to other types of educational experiences. Only complete answers for educational experiences which you have previously encountered. If you have never encountereda certain typeof education, then please indicate N/A (not applicable) for that answer.

	Less Effective	**Equally Effective**	**More Effective**	**N/A**
Compared to **traditional didactic teaching** (ex: power point), augmented reality is:	○	○	○	○
Compared to **online learning** (ex: blackboard), augmented reality is:	○	○	○	○

Compared to **bedside teaching** (ex: precepting in the patient room), augmented reality is:	**O**	**O**	**O**	**O**
Compared to **standardized patient encounters** (ex: actor patient scenarios), augmented reality is:	**O**	**O**	**O**	**O**
Compared to **low fidelity manikin simulations** (ex: plastic model with no additional functionality), augmented reality is:	**O**	**O**	**O**	**O**
Compared to **high fidelity manikin simulations** (ex: manikins that you can listen to and feel pulses), augmented reality is:	**O**	**O**	**O**	**O**
Compared to **reading** (ex: textbook), augmented reality is:	**O**	**O**	**O**	**O**