Using Virtual Reality Simulation Environments to Assess Competence for Emergency Medicine Learners

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ABSTRACT

Immersive learning environments that use virtual simulation (VS) technology are increasingly relevant as medical learners train in an environment of restricted clinical training hours and a heightened focus on patient safety. We conducted a consensus process with a breakout group of the 2017 Academic Emergency Medicine Consensus Conference "Catalyzing System Change Through Health Care Simulation: Systems, Competency, and Outcomes." This group examined the current uses of VS in training and assessment, including limitations and challenges in implementing VS into medical education curricula. We discuss the role of virtual environments in formative and summative assessment. Finally, we offer recommended areas of focus for future research examining VS technology for assessment, including high-stakes assessment in medical education. Specifically, we discuss needs for determination of areas of focus for VS training and assessment, development and exploration of virtual platforms, automated feedback within such platforms, and evaluation of effectiveness and validity of VS education.

Simulation technology is increasingly used for training medical professionals and is anticipated to become more relevant in the setting of restricted clinical training hours and heightened focus on patient safety. Virtual simulation (VS) environments add convenience and flexibility and increase the ability to scale and distribute simulations widely with lower costs. As with traditional simulation, the degree of fidelity is driven by the learning objectives. In this article, we use the term VS to refer to virtual reality (VR)-, augmented reality (AR)-, or serious games (SG)-based platforms that create an immersive learning environment; the boundaries between such technologies are difficult to define and for academic purposes these terms have been used interchangeably.[1] Table 1 provides specific definitions of terms related to VS.[2–4] Current literature examining virtual environments includes a breadth of clinical content, diverse learner audiences, and varied and rapidly evolving applied technologies. It is imperative that VS research draws upon literature regarding the acquisition of expertise and mastery learning and proven theories in educational and

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Table 1
Standard Definition of Terms in VS

Screen-based simulation	A simulation presented on a computer screen using graphical images and text.
VS	A screen-based simulation where the graphics, sound, and navigation emphasize the 3D nature of the environment.
VR	Use of immersive, highly visual, 3D characteristics to replicate real-life situations; typically incorporates physical or other interfaces such as a head-mounted display, motion sensors, or haptic devices in addition to computer keyboard, mouse, speech, and voice recognition. The user interacts as if it takes place in the real world and the focus of the interaction remains in the digital environment.
AR	A type of VR in which synthetic stimuli are superimposed on real-world objects (overlays digital computer-generated information on objects or places in the real world) for the purpose of enhancing the user experience; may include head-mounted display, overlays of computer screens, wearable computers, or displays projected onto humans and mannequins. The focus of the interaction of the performed task lies within the real world instead of the digital environment.
VSP	Avatar-based representations of human standardized patients that can converse with learners using natural language.
SG	Interactive computer applications simulating real-world events designed for a primary educational purpose rather than pure entertainment. Present challenging goals; are engaging to the user; incorporate some scoring mechanism; and supply the user with skills, knowledge, or attitudes useful in reality.

AR = augmented reality; SG = serious games; VR = virtual reality; VS = virtual simulation; VSP = virtual standardized patient.

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	Interactions of participants with focus on critical analysis and reflection
Navigation	Sequenced directions and guiding aids
Identical elements	Accurate visual representations of clinical artifacts
Stimulus variability	Variety of relevant cueing items as found in the clinical setting
Feedback	Prompts to facilitate progression through the activity
Social context	Collaborative synchronous participation of the players

*Adapted from Lemheney AJ, et al. Developing virtual reality simulations for office-based medical emergencies. J Virtual Worlds Res 2016;9:1–18. Copyright 2016 by Springer. Reprinted with permission.

cognitive psychology literature.[5–8] In framing our research questions, we limit our background to specific references related to applied VS technology.

CURRENT APPLICATION OF VS IN TRAINING AND ASSESSMENT

Screen-based simulation training enhances learning outcomes.[9–12] VR simulation applications improve learning outcomes for a variety of surgical procedures[3,13–18] and differentiate levels of education and skill in surgical procedures.[19–26] VR and AR create enhanced learning environments that can increase learner motivation/engagement, enhance spatial knowledge representation, improve contextualization of learning, and develop superior technical abilities.[27]

The representational fidelity of 3D virtual environments, interactive potential, and user immersion impact training effectiveness.[28–31] One must consider many variables and design elements when applying VS technology (Table 2). Educators must predetermine the duration; pace; level of realism and standardization; and amount and timing of feedback, coaching, or debriefing.[31] These decisions should be aligned with the level of the learner and training objectives to help ensure training effectiveness. A variety of popular virtual platforms focus on individual or team scenario-driven learning (Table 3).

Serious games platforms utilizing virtual standardized patients (VSPs) are increasing in use for health care training and assessment[32–36] SG-based training develops situational awareness for medical trainees.[37] Improvements in automated speech recognition and natural language processing engines allow trainees to communicate with VSPs using natural language conversations rather than selecting predefined questions.[38,39] Accuracy of VSP responses is increasing, but is impacted by the complexity of cases.[40,41] VSPs can simulate clinical presentations with a high degree of consistency and realism and provide valid and reliable representations of live patients for the purpose of conducting medical interviews.[41–44] VSPs are useful for assessing communication with patients, history

Table 3
Characteristics of Popular Virtual Simulation Platforms Focused on Individual or Team Scenario-Driven Learning

Platform*	Single or Multi-player	Automated Patient Avatar	Dynamic Physiology	Communication Capabilities	Area of Focus	Automated Feedback
USC Standard Patient©[40] www.ict.usc.edu	Single	Yes	No	Free text (voice available, but less accurate)	History and physical exam, differential diagnosis, and treatment choices	Optional real- time feedback during encounter, detailed categorized feedback at end of case
Simtabs© www.simtabs.com	Single	Yes	Yes	Select choices	Varies based on learning objective	Yes
I-Human Patients® www.i-human.com	Single	Yes	No	Select choices	Branching decision logic allows for multiple visits and to experience variety of outcomes	Yes
Unity 3D©[41] https://unity3d.com	Multi	Yes	Optional	Verbal communication possible	Varies based on learning objectives	Optional
Second Life® http://secondlife.com	Multi	No	Optional	Verbal communication possible	Varies based on learning objective, open source platform	Optional
Clinispace© http://virtualsimcenter. clinispace.com	Multi	Yes	Yes	Patient automated, team played by team members	Team training in any health setting	Optional
Virtual Heroes® www.virtualheroes.com	Either	Yes	Yes	Select choices	Team training prehospital, and disaster management	Optional
Anesoft©[9,10] http://anesoft.com/	Single	Yes (basic)	Yes	Neither	Choose interventions	
HeartCode®[12] www.cpr.heart.org	Single, basic team avatars	Yes (basic)	Yes	Select choices	Basic and advanced life support algorithms	Detailed feedback on critical actions and timing
Mursion® https://mursion.com	Single	Optional	No	Verbal communication possible	Basic history and physical exam, counseling	

*This table offers limited examples of popular virtual simulation platforms and is not meant to provide a comprehensive list.

taking, formulation of differential diagnosis, clinical decision making, and patient education.[4,45–49] VSPs offer precise stimulus control, are available at any time and location, and potentially offer more reliable and bias-free assessments than traditional standardized patients.[4] Use of VSPs shows promise in future assessment of nonprocedural clinical skills for medical professionals such as higher-level processing necessary for clinical decision making and empathy.[50–52]

Instructional design and curricular integration are barriers that limit the current use of VSPs.[51] A survey of U.S. and Canadian medical schools in 2005 found 24% of institutions were developing VSPs with significant overlap in content or objectives, suggesting that broader access and cooperative development could enhance medical education curricula and decrease resource utilization.[53] Educators would benefit from a reduced case authoring burden. Development of prepopulated questions/responses and authoring tools that provide simplified input of unique case data and modification of existing preauthored responses allow efficient instructional design.[4] Improved authoring systems may result in shared case libraries and confer benefits from language processing learning across multiple scenarios.

TRAINING AND ASSESSMENT OF EMERGENCY MEDICINE LEARNERS USING VS

High-fidelity simulation-based assessment is increasing in emergency medicine (EM) and offers a mechanism for formative assessment of Accreditation Council for Graduate Medical Education (ACGME) outcomes-based milestones with limited evidence regarding summative assessment of milestones or use as a remediation tool.[54] Investigation of VS technology with regard to assessment of medical trainees has traditionally focused on surgical and procedural specialties and research applying VS-based assessments to EM practice is limited.[3,13–26] VS has been incorporated in multiuser team assessment. A pilot study of medical learners participating in a team experience in a virtual emergency department versus traditional patient simulator showed no differences in performance of basic principles of team leadership or ATLS management.[55] EM resident performance on a traditional oral examination was equivalent to performance on an avatar-based examination. Outcomes included critical action scores and scores on eight competency categories, including those focusing on communication (a unique consideration for assessment using VS).[56]

Virtual simulation is a viable platform for high-stakes assessment. The most widespread example of screen-based assessment is the USMLE step 3 examination.[57,58] In EM, the ABEM reported early evidence supporting validity of the computer-based enhanced oral examination (eOral).[59] While these efforts are promising, research is needed to determine the degree to which learners must be oriented to VS technology to ensure assessments are measuring clinical skill and not technical facility. High-stakes assessment incorporating VS will require reproducible scenarios with reliable and valid assessment tools.[60]

FUTURE ASSESSMENT USING VS: RECOMMENDED AREAS OF FUTURE RESEARCH ON TRAINING AND ASSESSMENT IN VIRTUAL ENVIRONMENTS

Which Educational Areas in EM Should Be the Focus of VS Interventions?

For EM educators, it will be important to determine optimal applications of VS technology. Multiple professional bodies have endorsed the importance of interprofessional communication within health care teams[61] and multiuser immersive VR simulations provide an excellent platform to enable multidisciplinary and interprofessional teams to rehearse and debrief.[55,62] Improvements in artificial intelligence and natural language processing can facilitate assessment for communications between trainee and nonplayer character(s) and between team members. The specific aspects of teamwork competency best trained and assessed with multiplayer team simulations should be established.

Virtual reality is ideal for training in high-acuity, low-frequency events including disaster and mass casualty events such as response to chemical, biologic, nuclear, and explosive agents.[63,64] Virtual simulated mass casualty incidents meet the educational objectives equivalent to traditional simulation and allow for more frequent practice of these skills.[65] Similarly, VS supports formative assessment in areas of rarely encountered clinical events or procedures.[26]

Research supports the use of VS-based simulations to effectively assess procedural skill.[3,13–26] However, one of the major challenges associated with creating VS-based procedural simulators is the need to provide users with realistic tactile sensation, or haptic feedback. Haptics allow the learner to sense a physical object and manipulate that object in a realistic fashion. Without haptics, learners do not have a sense of the amount of force they are applying to a scalpel or the resistance they would normally encounter during a procedure. For procedurally focused VS applications, the lack of robust haptic technology represents a major barrier.[26,66] We must determine which areas of EM training will benefit from the special assistance of haptics training, three-dimensional simulation, AR, and other special visualization technologies.

Recent policy statements support using simulation to evaluate ACGME milestones and the Association of American Medical Colleges (AAMC) entrustable professional activities (EPAs).[67–69] VS facilitates the process of obtaining the multiple spaced observations deemed necessary to ensure competency.[70] VS also provides a potential platform for assessment of EPAs and milestones that are currently difficult to assess through direct observation such as competencies related to interpersonal and communications skills or patient care areas like task switching. Given the potential for VSPs in assessment of nonprocedural clinical skills such as higher level processing and clinical decision making, VS may be ideal for assessment of advanced cognitive skills required for EM triage, prioritization, and multipatient management.[50–52] Ultimately, we must determine which ACGME milestones, AAMC EPAs, or nursing and paramedic competencies are best addressed with VS.

How Can Development of Future VS Platforms Best Serve Training and Assessment Needs?

Recent advances in VR technology allow for the creation of highly immersive experiences at lower costs than earlier systems. Existing platforms vary in strengths, weaknesses, and areas of current

Table 4
Features of the Ultimate Learning Platform: A Comparison of Mannequin-based Learning (MBL), Procedural Simulation (Procedural), Single-player Games-based Learning (GBL single), and Multiplayer Games-based Learning (GBL Multi)

Features of the Ultimate Learning Platform	MBL	Procedural	GBL (single)	GBL (multi)
Interactive	x	X	x	X
Participate individually		X	x	
Participate in teams	x			X
Peer instruction	x		x	X
Engages multiple senses	x	x	x	X
Sense of touch	x	x		
Offers immediate feedback	x	x	x	X
Opportunity for reflection	x	x	x	X
Self-paced reflection		x	x	
Chaining		x	x	X
Individual remediation		x	x	
Inexpensive to build				
Inexpensive to maintain			x	X
Accessible 24/7/365			x	X
Accessible from anywhere			x	X
Mobile delivery			x	X
Learning at the point of care	x		x	X
On-demand/just-in-time delivery			x	
Self-directed		x	x	
Facilitator independent		x	x	X
Self-paced learning		x	x	
Scalable			x	X
Distributable			x	X
Personalized			x	
Adaptive		x	x	
Adjustable levels of fidelity		x	x	
Back-end analytics		x	x	X
Automated assessment		x	x	X
Expandable content	x		x	X
Extensible platform			x	X
Reusable assets	x	x	x	X
Augment reality		x	x	X
Manipulate time	x	x	x	X
Standardize experience		x	x	X
Learners remain anonymous		x	x	X

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application. Table 4 illustrates ideal characteristics of virtual learning platforms. Some degree of faculty development will be required regardless of which platform(s) is/are chosen. It may be more efficient to have faculty provide learning objectives and case details and leave the technical components of programming to others. Substantial work remains to define a process for developing VS platforms that meet the particular needs of learners in EM.

As new platforms are developed, there are specific characteristics that may optimize learning opportunities in EM. Platforms should support rapid development of new cases to facilitate training responses to emerging problems (e.g., disaster or outbreak situations). Ideally, VS platforms would be mobile and easily deployed to reach larger and more varied audiences. Educators need to determine how to develop and share virtual content in the most efficient and cost-effective manner to support disseminated use of such platforms.

Virtual simulation platforms should incorporate perceptual adaptive learning into trainee assessments.[71–74]

Perceptual adaptive learning modifies future simulated events based on whether the learner has responded appropriately to past events. Thus, the level of difficulty for VS-based assessments can be rapidly modified in response to learner performance. VSs that incorporate perceptual adaptive learning can support a more customized learning experience. Although challenging and resource-intensive, making truly adaptive VSPs could prove highly effective for formative assessment.

How Can Automated Feedback Within VS Benefit Learner Assessment?

Virtual simulation–based simulations can provide real-time, embedded feedback. More traditional mannequin and simulated patient-based simulations require direct observation by faculty to generate feedback. This can be costly and may limit simulation implementation in remote areas. Currently, VS is best suited for the delivery of embedded feedback focusing on treatment decisions and diagnostic reasoning. Currently, limitations in existing artificial intelligence and natural language processing technology restrict the ability to automate feedback for communication-based skills. With improved technology, typed or spoken learner dialogue within VS could trigger automated feedback on communication skills. Research is required to determine the most effective way to deliver feedback in VS systems. Specific elements of debriefing or hybrid debriefing models that combine virtual experience with real "debriefers" (in person or as live avatars) may enhance the educational experience. In the future, VS may extend feedback capabilities to include skills such as efficiency in communication and cost-effectiveness of patient care.

How Can We Evaluate Effectiveness and Validity of VS Technology?

The most important research questions will focus on outcomes that involve process change or direct patient outcomes. However, educational effectiveness is the first step before moving to more resource-intense trials and educational effectiveness may be the only criteria needed if the educational cost–benefit ratio is desirable. We must determine whether VS achieves the same educational outcomes versus traditional methods as measured by markers such as learning curve efficiency, performance testing, skills decay testing, and other educational outcomes. Further, we must assess whether VS achieves the same or better behavior/process change and patient care outcomes when compared to traditional educational methods. Ultimately, we must determine whether VS leads to more cost-effective education within a multicenter effort, either as part of a focused educational trial or as part of a clinical care process change effort.

The process of developing reliable assessments supported by evidence of validity for simulation-based assessment is well described.[75] While beyond the scope of this article, it will be important to understand how researchers can apply this framework to VS assessments. Validation studies for VS technology in training and assessment are limited. Some SGs are supported by evidence of validity.[55,76–81] Mohan et al.[82,83] demonstrated validity for a SG developed to train emergency physicians in trauma triage and provide an example of sound methods to investigate a virtual gaming intervention. Ideally VS should demonstrate the same validity and reliability as current assessments.[75] Further investigation of assessment capabilities and limitations of virtual technologies remains a priority for future research in EM.

LOGISTIC CHALLENGES RELATED TO VS

There are unique challenges when incorporating VS for training and assessment (Figure 1). Major considerations include startup resources for platform acquisition or customization, content development and maintenance, and data management. There are administrative needs related to login information, training, and performance tracking. Additionally, faculty will likely require specific training to enable them to effectively operate and implement VS-based training platforms. The resources and time required for such train-the-trainer programs could be significant and must be considered when choosing to develop VS-based curricula.

Certain formats of VS can address some of the challenges associated with delivering simulation-based training to large numbers of learners across health care systems. However, current VS design approaches are not standardized or well described, limiting the ability to adapt training from one application to another. Increasing access to or awareness of existing authoring tools may remove a real or perceived barrier by decreasing the initial startup time associated with creation of VS scenarios. Hardware costs such as screens or head-mounted displays (HMDs) may limit widespread VS implementation, although the incorporation of VS into mainstream gaming is driving low-

Considerations While Choosing a Virtual Platform for Assessment

1. What are the learning objectives?
2. How many learners must be represented?
3. Will the patient or health care providers be automated or voiced by an actor?
4. Is dynamic physiology important for the learning objective?
5. Is it important how questions are asked or would simply choosing from a list of questions be adequate?
6. Is more than one visit needed over time? Is more than one evaluation needed within a visit?

Figure 1. Considerations while choosing a virtual platform for assessment.

cost, easily accessible technology solutions. Educators often encounter information technology barriers such as firewalls. Learning management systems that can incorporate simulation-based curricula would help to address this issue.

Rapidly changing VS technology presents a major challenge to establishing VS-based curricula. For the purposes of assessment, it may be necessary for leading organizations in the health care community to commit to using a specific platform. This would reduce the need to continuously train content developers and learners on new formats. Additionally, it would facilitate the collection of validity evidence across institutions and could inform potential application for more summative assessment.

The consensus group spent a significant amount of time discussing issues related to resources, cost, and return on investment. Several of these issues are addressed above. The overarching theme noted was the relatively high resource needs associated with VS curricula specific for a small number of users. If VS training can be adapted for nurses, EMS providers, and learners from other disciplines, the cost per learner would markedly decrease. Moreover, vendors are more likely to invest startup funds in a product that has wide application beyond EM. If research can link VS training with improved patient outcomes, then health care systems might be motivated to provide significant financial support for VS development.

CONCLUSION

Virtual simulation can address several challenges that limit simulation-based training across health care systems. Research is needed to identify best practices, determine optimal technologies, and facilitate rapid adoption. This work highlights priorities for research efforts and identifies potential logistic barriers and solutions that should be further explored. Continued collaboration between educators, engineers, and clinicians is critical to advancing the development and implementation of virtual simulation–based training in emergency medicine.

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APPENDIX A

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