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

Citation

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Accessibility
Cavazza et al. 2013 Interactive Storytelling VP cases to teach physician-patient interaction, communication and empathy. Descriptive Medical students in USA. None. None. Development of SG described.

Chan et al. 2012 Ultrasound-guided needle placement Technical trainer with virtual tools and tissues to teach ultrasound-guided needle placement. RCT: SG vs. C (self-study) Radiology residents in China; n=21. Post testing via live simulation. 4, 5 Increased success rate for SG vs. C [mean 33.3% vs. 68.2% (+34.9%) vs. 20.2% to 37.8% (+17.6%)]. Reduced completion time for SG vs. C [51.5-34.8 vs. 16.9 s] and 54.3-42.8 s (+11.5 s). Validation with only inexperienced users' post-test scores improved vs. pre-test.

Cowan et al. 2011 Off-pump Coronary Artery Bypass Multi-player VE, teaching the steps of off-pump coronary artery bypass. Descriptive Cardiac surgeons in Canada. None. None. Development of SG described.

Cowan et al. 2010 Total Knee Arthroscopy (TKA) Game VE teaching the steps of a TKA, with MCO sub-games interspersed. Survey Medical students in South Africa. Survey. 1, 2, 3 Participants rated the SG easy to use, intuitive, stimulating.

Craig et al. 2014 Virtual Pathology Instructor (V-PIN) Interactive CBS with MCO: branched narratives with virtual pathology materials that guide learners through diagnosis. Quasi-experimental (SG at various points in curriculum). Medical students in USA; n=185. Post-intervention MCO, SG performance, survey. 1, 2, 3, 5 Significant pre-test to post-test improvement in scores for two cases (mean 3.8 vs. 4.2, p=0.0007; 1.9 vs. 3.0, p=0.0001), but not the third (mean 2.5 vs. 2.3, p=0.12). Maximum score for traditional teaching with SG vs. SG alone (4.2 vs. 3.0, p=0.001). No significant difference in time on task, total steps, score, and requests for help when SG placed before vs. after testing, 66% felt that "V-PIN cases helped me better understand the concepts."

Creutzfeldt et al. 2006, 2010, 2012, 2014 Multiplayer Virtual World CPR Game Multiplayer VE with 4 short patient-based scenarios where learners care for cardiac arrest victims in teams of three, communicating via microphone. Learners approach and examine victim, and perform resuscitation in communication with 911 dispatcher. Four studies: Quasi-experimental. T(26)=2.294; p=0.027. RCT: CPR training followed by SG refresher 6 vs. 16mo prior to assessment vs. control (no refresher). Large Students reported enjoyment and learning with SG. Self-efficacy increased after first [5.9 to 6.57 (p=0.01)] and second SG session [8.0 to 6.77 (p=0.03)]. Mean perceived concentration increased [54.2/100 to 66.6/100 (p=0.006)], with low to moderate mental strain (mean=2.6). Significant increase in self-reported situational awareness (SA) [3.4 (2.4) to 3.9 (1.4), p<0.001], and correlation between SA and concentration (p=0.61) (Spearman rank order correlation, p=0.001). Decreased mean elapsed time between first and last scenarios until start of examination (42.8 to 16.2s), ventilation (66.8 to 44s), and chest compressions (60 to 50s). No decrease in time to call for help. Mean compression fraction increased (42% to 52%) and mean occurrence of protocol violations decreased (5.5 to 1.8). Higher scores in 6mo vs. control [93 (+11%) to 65 (+28%) (p=0.05)], 18mo scores: 73 (+23%) vs. 92 (+28%). Mean guideline violations 0.2 (±0.5), 34% for control, 18mo, and 6mo (p=0.001) or control vs. 18mo or 6mo.

Davidy et al. 2011 Electrolyte Workshop VP cases simulating electrolyte abnormalities, augmented with multimedia. Physiology modeled. Survey Residents, physicians in South Africa; n=16. Usability survey. 1, 2, 3 Mean SUS 78.4 +/- 13.8. 16/16 would use the SG often, 15/16 would recommend to others. 13/16 found it easy to use and well-integrated, while 2/16 found it cumbersome and 3/16 found navigation difficult. 15/16 found the content scientifically sound and interesting, 9/16 found it realistic. 14/16 reported concept clarity and increased understanding.

De Leo et al. 2014 Game Medical Team Training (GaMMaT) Multi-player VE teaching inter-professional acute care (microphone communication). Learners manage virtual military and civilian casualties. VP operated remotely by live person. Psychological mapped. Survey Air Force National Guard Medical Service in USA, n=29. Survey. 1, 2, 3 Comparing user characteristics via Independent Television Commission Sense of Presence Inventory using Kendall T test showed: characteristics “how often you play video games” (T(26)=0.458, p=0.65) and “television/film production knowledge” (T(27)=0.516, p=0.01) were significantly related to negative effects (dizziness, nausea, headache, and eyestrain during SG experience). The user characteristic “knowledge of virtual reality” was significantly related to engagement (T(26)=4.53, p<0.01) and negative effects (T(26)=−0.404, p<0.05).

Delassober et al. 2010 Cardiac Arrest! VE where users manage patients requiring advanced cardiac life support skills. RCT: reading (R) vs. live simulation (S) vs. SG and multimedia group (M) Paramedic students in India, n=117. Pre/post MCO, cardiac arrest live simulation, re-testing at 3 weeks, survey. 1, 2, 3, 5 Significantly higher increases in live simulation post-test scores for S vs. R and M groups compared to pre-test (+9% S vs. +5% R vs. +2% M, p=0.05). Significantly higher increases in MCO post-test scores for M vs. R, no difference compared to S (+5% M, +3% S, +2% R, p=0.05 for R only). Significantly higher increases in live simulation post-test scores at 3 weeks for M vs. R, no difference compared to S (+6% S, +1% M, -1% R, p=0.05 for R only). Significantly higher increases in MCO post-test scores at 3 weeks for M vs. R and vs. S (+5% vs. 0%, p=0.05). 95% of S and 84% of M felt their modality should be incorporated into the curriculum. 95% of S and 89% of M reported enjoyment.

Dev et al. 2011 ClinSpace VE of emergency department. Physiology modeled. Quasi-experimental Physicians, students. Survey. 1, 2, 3 Although numbers not reported, users rated the game as easy to use, realistic, and stimulating.

Diehl 2013 InsuOnline VE with diabetic VP. Embedded quizzing and multimedia assets. Comparison trial: Lecture (L) vs. SG. Medical students and residents in USA; n=20, n=41. Pre/post MCO, re-testing at 3 months. 1, 2, 3, 5 Development of SG and future studies described. Mean SUS score of 88/100 for prototype, 92.5% for beta version. Users found the SG to be fun, engaging, challenging, relevant, realistic, and preferable to a lecture. Users said the SG increased knowledge of and confidence with diabetes and insulin, that it would impact how they treated patients with diabetes. Mean knowledge/skills score improved from 86% to 89% in L group (n=23; p<0.001), from 61% to 90% in SG group (n=18; p<0.001). At 3 months, mean score decreased (80% in L group, 78% in SG group; p=0.001 for both), but was significantly higher than baseline (p=0.001 for both). No difference between SG and L groups immediately or 3 months post. Score increment was better for SG (29%) than L (21%); p=0.04). Benefits improved in SG group only.
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<td>Janssen et al.</td>
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<td>Medical students in UK: n=47.</td>
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<td>Quasi-experimental</td>
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<td>Pre/post test: midterm vs. final exam scores.</td>
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<td>Residents, None</td>
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LeRoy et al.2014 Space-medical evacuation (SE) blood pressure (BP) control game

Competitive MCQ game, learners earn points at regular intervals and relative scores posted to foster competition among peers. BP recording of hypertensive patients evaluated. 

RCT: SG users vs. control (identical content online) 

Primary care clinicians in the USA; n=111. 

Pre/post MCQ at 14 weeks, time to BP target in hypertensive patients. 

5, 7

Higher post-test scores in SE group vs. control group (90% vs. 78% (SD 19), respectively; Cohen d 0.8, p<0.001). Median time to BP target in 17,866 hypertensive periods was decreased in SE vs. control groups (142 vs. 148 days, p=0.018). Hazard ratio for time to BP target in SE group was 1.043 (95% CI, 1.007–1.081; P=0.018). The number of hypertensive episodes needed to treat to normalize one additional patient’s BP was 67.8. 

The number of clinicians needed to teach to achieve this was 0.43.

Kerfoot et al., 2012 SE Urology Content Game

Competitive MCQ game on core urology content, 2 MCQs with feedback emailed daily. MCQ re-sent in 2 or 6 weeks if answered incorrectly and correctly, respectively. Competition fostered by posting relative performance. 

Quasi-experimental 

Urology residents in USA and Canada; n=931.

Baseline scores and completion rates within SE compared with standardised exam scores. 

1, 2, 3

Baseline scores (median 62%, interquartile range [IQR] 17%) correlated with scores on 2008 American Urological Association in-service examination (ISE08, ISE09). 2009 American Board of Urology qualifying examination (QE09) (p<0.76, 0.46, and 0.64, respectively; all p<0.001). Baseline scores varied by gender, country, degree, and training year (all p<0.001). Completion scores (median 100%, IQR 2%) correlated with ISE08 and ISE09 scores (r<0.35, r<0.001 for both). Median completion score was 100% (IQR 2%). Completion scores varied by training, ranging from a median 99% (IQR 4%) for year 1 to 100% (IQR 1%) for year 4 residents (p<0.001). 72% surveyed requested future SE games.

Kerfoot et al.2012 SE Pre-Clinical Content Game

Competitive MCQ game on pre-clinical content, 2 MCQ with feedback emailed daily. MCQ re-sent over time and relative scores posted to foster competition.

Quasi-experimental 

Medical students in the USA; n=731.

Baseline scores and completion rates within SE. 

1, 2, 3

Median baseline score was 53% (IQR 16) and varied significantly by year (p<0.001, max =2.08), school (p=0.001, dmax = 0.75), and gender (p<0.01, d = 0.38). Median completion score was 93% (IQR 12) and varied significantly by year (p<0.001, dmax = 1.12), school (p<0.001, dmax = 0.34), and age (p=0.019, dmax = 0.43). Scores did not differ significantly between years 3 and 4. 70% surveyed requested future SE games.

Kerfoot et al.2012 SE Urology Continuing Medical Education Guidelines Game

Competitive MCQ game on urology guidelines, 2 MCQ with feedback emailed daily. MCQ re-sent over time and relative scores posted to foster competition. 

RCT: 2 MCQs every 2 days, vs. 4 MCQs every 4 days 

Physicians worldwide; n=1470. 

Baseline scores and completion rates within SE. 

1, 2, 3

Median baseline score was 46% (IQR 17), and median completion score was 98% (IQR 25) for SE, 4 MCQ every 4 day group performed worse than 2 MCQ every 2 days (d = 0.43, p<0.001). 76% of participants requested to participate in future SE games.

Kizakevich et al.2007 Sim-Patient<sup>TM</sup> 

VE with single and multiple-casualty cases (bioterrorism, trauma, improvised explosive device). Learners apply triage tags and manage cases. Physiology modeled. 

Survey 

Military physicians in the USA; n=31. 

Survey. 

1, 2, 3

Surveyed participants rated simulation realism and navigation a mean of 4.40 (out of 5, SD 0.43), simulation content and responsiveness 4.42 (SD 0.04), simulation learning content 4.41 (SD 0.20).

Knight et al.2010 Triage Trainer

VE of major incident scenario where users perform medical checks, tag and assess multiple patients at a time. 

RCT: SG vs. C (card sort exercise) 

Physicians, nurses, paramedics in the UK; n=91. 

Post testing with live simulation. 

5

Significantly improved tagging and step accuracy for SG vs. C group (Chi2 = 47.8, p<0.001). No difference in time to triage between the two groups (456 ± 62 s vs. 435 ± 74 s, p=0.155).

Kurenov et al.2009 Burn Center

Mass bomb blast casualty disaster VE. Learners stabilize, sort, tag and transport victims, care for patients in intensive care unit. 

Descriptive 

Trauma surgeons, nurses, therapists in the USA. 

None. 

None. 

Positive correlation between training with Burn Center and performance in a traditional lecture course.

Lagro et al.2014 GeriatrIX

Geriatric clinic VE. Users care for VP with fatigue due to iron-deficiency anemia. Users scored on appropriateness and cost-efficiency of care. 

RCT: SG vs. C (self-study) 

Medical students in the Netherlands; n=134. 

Pre/post MCQ, confidence survey. 

1, 2, 3, 5

Significantly higher post-test scores for SG vs. C in cost consciousness (cost deviation: 13.5 +/- 3.6 vs. 15.4 +/- 3.6, p<0.005). Significantly higher self-perceived knowledge in SG vs. C group for appropriateness/ cost of care (effect sizes 1.0, and 1.2). No difference for geriatric content. Most felt SG was clear (3.8/5±0.8), enjoyed it (4.0/5±0.9), wanted to finish the SG (4.1/5±0.7). SG was considered it a safe environment (4.1/5±0.8), and felt clinicians needed to teach to achieve this was 0.43.

LeBoy et al.2008 Virtual ED II

Multipayer VE with cases simulating Sarin exposure or radioactive bomb blast. Communication through microphone. 

Survey 

Physicians, nurses in the USA; n=13. 

Satisfaction survey. 

1, 2, 3

62% reported a change in their feelings about working in an ED team. Mean ratings showed users felt immersed (3.4/5±0.8) and the SG increased confidence in ability to respond to trauma (2.0/5 before SG; 3.0/5 after SG). Most thought the SG would be useful for learning teamwork (mean = 3.77/5) and clinical skills (mean = 3.15/5). Comments indicate users perceived the SG as realistic.

LeBoy et al.2008 Pennsylvx City

Multipayer VE of a triage area after an explosion. Communication through microphone. 

Survey 

Paramedics, physicians, nurses in the USA; n=16. 

Satisfaction survey. 

1, 2, 3

75% and 56% of participants thought the SG was useful for refresher training and initial training, respectively. 

62% thought the SG was as/more effective than traditional methods.

Lim et al.2008 eNLG (online Neurological Localisation Game) 

Modified essay and MCQ of patients with neurological problems, with learners examining and managing patients. Embedded videos. 

Survey 

Medical students in Singapore; n=76. 

Satisfaction survey. 

1, 2, 3

93.4% of participants felt that the eNLG helped them better understand neurological localization principles, 90.7% believed the question-based format was suitable, 96.1% liked the use of videotaped vignettes, and 98.6% requested more eNLG scenarios in the future. 42.1% felt the eNLG could replace regular bedside teaching.
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<td>2015</td>
<td>Lin et al.</td>
<td>SICKO (Surgical Improvement of Clinical Outcomes)</td>
<td>Same game format as Seprix (above), but with timed surgical CBS. Learner triages and prioritizes care, decides whether or not to operate, makes intraoperative decisions.</td>
<td>Validation study: comparison of performance vs. skill level. Medical students, residents and surgeons in USA; n=49. Performance during gameplay compared across skill level, survey. 1, 2, 3, 4 Mean total SG scores for the novice, junior resident, senior resident, and expert groups were 5,461; 8,519; 11,404; and 13,913, respectively (p = 0.01). Usability survey results were positive, with mean scores ranging from 3.52 to 4.26 across ten questions.</td>
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<td>2013</td>
<td>McKenzie et al.</td>
<td>Game Informed Online Learning About Managing Aggression in Health Settings</td>
<td>Informed learning activity with VP scenarios involving aggression and balance of tasks in a healthcare setting. Embedded multimedia tools including video clips and external websites.</td>
<td>Comparison trial, not randomized: SG vs. control (didactic 90-minute teaching session) Clinical psychology students in UK; n=68. Case-based pre/post testing, self-reported confidence, usability survey. 1, 2, 3, 5, 6 Knowledge scores increased significantly following training in SG (t=5.564, df=34, p&lt;0.001) and control group (t=0.93, df=30, p=0.39). A split plot ANOVA illustrated a significant interaction effect between group and time: F(1.64)=11.11, p=0.001, p2=0.148, large effect size. Post-test scores vs. pre-test scores significantly higher for control vs. SG group. Confidence scores increased significantly following training in both SG (t=4.345, df=34, p&lt;0.001) and control group (t=4.642, df=30, p&lt;0.001). Mean educational activity rating scores for both groups were positive, but the control had significantly more positive scores than SG group in perception of learning tool as interesting. (t=3.654, df=41.88, p&lt;0.001) easy to follow (t=4.08, df=31.14, p&lt;0.001) and helpful (t=3.14, df=37.12, p&lt;0.003).</td>
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<td>2014</td>
<td>Mohamed et al.</td>
<td>ED Physician Decision Making</td>
<td>VE, users evaluate and manage cases simulating a busy ED shift. One version contained distracting cases and other audiovisual distractors. Timed, physiology modeled.</td>
<td>RCT: SG with distractors (cognitive load, CL) vs. SG without distractors (control, C) Emergency physicians in USA; n=209. Performance during game: transfer to trauma center, number of orders entered, time spent, CT scan rates. 4, 5 C was significantly more likely to appropriately transfer severely injured, hemodynamically unstable, and younger patients to trauma centers than CL group (40% C vs 25% CL, p=0.01; 49% C vs. 28% CL, p=0.01; 44% C vs. 27% CL, p=0.01). Same average number orders entered (10.9 C [SD 4.8] vs. 10.7 CL [SD 5.6], 95% CI p=0.74), but less time spent per case in C group (9.7 C [SD 7.1] vs. 11.7 C [SD 6.7] min, p=0.01). No difference in transfer of non-representative cases reliant on heuristics (45% C vs. 34% CL, p=0.20). Higher transfer of non-representative cases for C group (38% C vs. 26% CL, p=0.03). Overall physician transfer rates (31%) and CT scan rates (62%) were consistent with rates reported in literature for actual clinical practice (30%, 57.67%, respectively).</td>
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<td>2015</td>
<td>Moule et al.</td>
<td>VPs for cancer nursing education</td>
<td>VE simulation scenarios to teach nursing topics in caring for men with prostate cancer.</td>
<td>Survey Nurses, students Survey. The majority of respondents reported an increase in knowledge and suggested that they would recommend the resource to others.</td>
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<td>2015</td>
<td>Nicolaidou et al.</td>
<td>Virtual Emergency Telemedicine (VETM) Game</td>
<td>VE simulating cardiac emergencies through a telemedicine system.</td>
<td>Survey Ambulance crew nursing personnel in Cyprus, n=90. Survey. Along tested domains (user interface, difficulty level, feedback, educational value, user engagement, terminology), means ranged from 3.2/5 to 3.95/5. Analysis of log files showed a low success rate (20.6%). Participants described educational value and usefulness of the SG for pre- and post-education training (mean 3.93, SD 1.05), but identified confusing features and provided input for improving them.</td>
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<td>2007</td>
<td>Nossek et al.</td>
<td>Cancer Genetics Tower</td>
<td>VE, users progress through levels and complete patient-based tasks</td>
<td>Survey Medical students in USA; n=17. Survey. Participants rated the SG: excellent (10/17), good (9/17), or average (1/17). Participants found the quality of the graphics acceptable, and felt the SG held their attention. 14/17 felt the SG was helpful in learning the content and would be interested in using it more if content were added. Some found the speed of download too slow.</td>
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<td>2012</td>
<td>O'Heil et al.</td>
<td>GRAPHIC (Games Research Applied to Public Health with Innovative collaboration)</td>
<td>CBS, learners work collaboratively and individually to explore population oral health and the evidence for community initiatives, care for simulated 5-year-old patient in an inner city environment, Moodle.</td>
<td>Survey Dental students in UK; n. n=17. Satisfaction survey, SG completion. Positive feedback, not described. Learning outcomes achieved with all participants successfully passing the game. The software used in the construction of the game limited certain aspects of the interaction of the participants with the game.</td>
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<td>2014</td>
<td>Vankjipuram et al.</td>
<td>ACLS Virtual Reality Simulator</td>
<td>Multiplayer hospital VE, learners communicate via microphone with members of a team (randomly assigned to role) and perform ACLS on VP. CPR simulated via joystick. Two games with differences in amount of feedback (persuasion) given.</td>
<td>Two RCTs: Persuasive (P) vs. minimally persuasive (MP) SG. Control (didactic) vs. P vs. MP. SG. ACLS-certified physicians in US; n=965; n=148.6. Usability survey. 1st, 2nd, 3rd, 5th Higher mean usability (p=0.0944) and ease-of-use (p=0.0813) scores in MP compared to P. No difference in post-intervention performance control vs. P (p=0.37 for pulseless electric activity (PEA) and p=0.11 for ventricular fibrillation &amp; ventricular tachycardia (VFib/VTach)). No difference in performance in P vs. MP (p=0.1 for PEA, p=0.63 for VFib/VTach). Significant difference in performance in control vs. MP (p=0.05 for PEA and p=0.02 for VFib/VTach). The pre-post comparison of performances of the groups showed that control (p=0.017 for PEA, p=0.01 for VFib/VTach) and P (p=0.02 for PEA, p=0.048 for VFib/VTach) groups improved their performances significantly, whereas MP group did not (p=0.45 for PEA, p=0.46 for VFib/VTach).</td>
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<td>2010</td>
<td>Qin et al.</td>
<td>Stopping the Fountains pre-game + Virtual Orthopedic-Surgery Game</td>
<td>Operating room VE, learners manipulate surgical tools via haptic device. VP present with varying degrees of blood loss, users assess and manage. Physiology modeled.</td>
<td>RCT: SG with and without pre-training elements Orthopedic surgeons, students in China; n=21. Performance within SG: Time to complete blood management tasks. 5 SG with pre-training group outperformed SG without pre-training group in both completion time (p=0.01 by Wilcoxon-Mann-Whitney test and p=0.006 by Kruskal-Wallis test) and performance score (p=0.001 by Wilcoxon-Mann-Whitney test and p=0.001 by Kruskal-Wallis test).</td>
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<td>2013</td>
<td>Rondon et al.</td>
<td>Anatessis 2.0 Quiz</td>
<td>Interactive MCQ with multimedia, teaching anatomy and physiology of the spine, language, hearing, and swallowing mechanisms.</td>
<td>RCT: SG group vs. control (self-study) Speech Language &amp; Hearing students in Brazil; n=29. Pre/post MCQ, re-test at 6-months. 5, 6 Pre-test scores were significantly lower vs. post-test and long-term post-test scores. No significant differences between the groups post-test scores (p=0.176). When isolating specific topics within the assessment, SG group had significantly higher Anatomy (p=0.001) post-test scores. Pre- vs. long-term post-test scores indicated significant differences only for control group (p=0.042). No significant difference in post-test vs. long-term post-test scores.</td>
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<td>Type</td>
<td>Description</td>
<td>Control Group</td>
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<tr>
<td>Roy et al.</td>
<td>2006</td>
<td>Virtual Standardized Patients</td>
<td>VE where learners examine and care for VP: augmented multimedia. Communication via microphone.</td>
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<td>Schwaab et al.</td>
<td>2011</td>
<td>Second Life (SL) Case-Based Mock Emergency Medicine Board Examination</td>
<td>Hospital and examination room VE, learners manage cases, communicate via microphone with a faculty examiner at a remote computer (virtual patient). Mock oral American Board of Emergency Medicine examination.</td>
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<td>Stredney et al.</td>
<td>1996</td>
<td>Virtual Simulated Epidural Anesthesia</td>
<td>Hospital VE of a simulated patient’s back, for practicing epidural placement, with computer-generated needle.</td>
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<td>Sward et al.</td>
<td>2008</td>
<td>Pediatric Rotation Game</td>
<td>Testing environment of a web-based, interactive adaptation of an existing board game for general pediatric content.</td>
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<td>Tubej et al.</td>
<td>2015</td>
<td>Zinc Phosphate Cement Virtual Learning Object</td>
<td>Moodle-based VE teaching and testing handling of zinc phosphate cement for dental prostheses.</td>
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<tr>
<td>Youngblood et al.</td>
<td>2008</td>
<td>Virtual ED</td>
<td>Multiplayer emergency room VE, users examine and treat patients with a team. Users communicate through microphone. Physiology modeled.</td>
<td></td>
</tr>
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</table>

Abbreviations: SG = serious game, C = control, VE = virtual environment, VP = virtual patients, CBS = case-based simulation, RCT = randomized controlled trial, MCQ = multiple choice questions, SUS = System Usability Scale, s = seconds.