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Featured Article

Online Computer-Based Clinical Simulations: The Role of Visualizations

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computerized simulations;
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nursing education;
agent-based models;
visualization;
multimedia learning

Abstract

Background: One of the great promises of computer technology for education is the ability to combine text, sound, and visualizations to create multimedia-based simulations. Therefore, an understanding of whether and how to implement the variety of multimedia technology in nursing education is fundamental.

Method: This study compares the effectiveness of online computer-based simulations designed using three alternative multimedia approaches—video, animation, and agent-based visualizations—on learning of clinical reasoning skills. Participants in this study were undergraduate nursing students (n = 97).

Results: Learning gains were significantly higher for simulation that incorporated exploration of agent-based visualizations than for video- and animation-based visualizations. Interestingly, low achievers made significantly higher learning gains after learning with agent-based simulation than high academic achievers.

Conclusion(s): This study proposes that visualizations play an important role in the effectiveness of learning with computer-based multimedia environments. Learning with agent-based visualizations was superior to learning with animation- and video-based visualizations.

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Introduction

Computer-based online simulations that involve goal-based, digital learning activities can be used to train large number of nursing students, engaging them as active participants in any geographic location at any time of day (Dubovi, Levy & Dagan, 2017; Huun, 2018). The main typologies of online computer-based simulations are based on multimedia technology to represent visual and verbal material. The simulations often include authentic narrative case stories using simulated realistic medical situations, requiring cascaded decisions on the part of the learner (Cant & Cooper, 2014). To simulate those authentic clinical experiences, instructional designers often use different multimedia visualizations such as animated characters or filmed patient actors. Because nursing education programs are increasingly turning to computer-based simulations (Kleinheksel & Ritzhaupt, 2017), we must recognize that further research is needed to understand in depth the role

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that visualizations play in supporting nursing students' learning as part of computerized simulations.

Learning With Multimedia Visualizations

Key Points

- Computer-based online simulations incorporate a variety of multimedia technologies such as video, animation, and agent-based modeling paradigms.
- The learner's interactivity with and control of the visualizations can invoke different levels of cognitive engagement and thus influence learning outcomes.
- Agent-based simulations facilitate highly interactive actions that direct learners' attention, activate prior knowledge, and allow learners to adapt parameters of the visualizations to their individual learning needs, which in turn enhances the learning process.

One of the most profound changes in how information is presented to learners today is the burgeoning use of animated depictions and videos (Wouters, Paas, & van Merrienboer, 2008). Animation can be defined as the visualization of frames such that each frame appears as an alteration of the previous one, with a speed that creates the illusion of motion (Berney & Bétrancourt, 2016). In contrast to animated graphics, videos can provide learners explicit information by showing the motion and dynamics of real objects (Mayer & Moreno, 2002). However, because videos are captured rather than drawn, they are typically far less selective and flexible than animations in terms of what is, or can be, shown. In principle, such opportunities allow animations to provide a better match between how a subject is presented and the needs of learners (Lowe & Schnotz, 2015).

The potential educational benefits of learning in multimedia contexts rely on directing the perceptual attributes in alignment with the cognitive requirements (Mayer, 2005). Accordingly, there is a high possibility that while learning with dynamic frame-by-frame flow, important information can be lost from view before the learner has time to adequately select and process it. Therefore, research on interactive multimedia shows that making use of interactive manipulatable features can help learners flexibly interrogate the available information and diminish their cognitive load (Homer & Plass, 2014). Of special interest to this research are agent-based modeling interactive visualizations.

Agent-based modeling is a computerized modeling paradigm that emphasizes multilevel examination of complex, multiagent systems. In contrast to story-line animations or videos, agent-based models are dynamic representations and therefore enable learners to explore and manipulate the visualizations. By design, these systems enable a learner to specify, control, and observe how any individual visualizations (called agents) in the system will behave as well as how the entire system of agents produces an emergent result. Exploration of agent-based models encourages causal emergent thinking through which students are able to understand the mechanisms driving these patterns (Dickes, Sengupta, Farris, & Basu, 2016; Levy & Wilensky, 2008).

Cognitive Engagement

Following the fact that "active learning" is defined as engaging cognitively, Chi and her colleagues proposed a four-level cognitive-engagement framework, the ICAP (which stands for interactive, constructive, active, and passive) framework to operationalize and differentialize the degrees of cognitive engagement (Chi & Wylie, 2014). This empirically grounded theoretical framework suggests that different modes of engagement predict different levels of learning (Chi et al., 2018).

Specifically, the ICAP postulates that Interactive engagement, demonstrated by cogenerative collaborative behaviors such as debate or a joint dialogue, is superior for learning to Constructive engagement, indicated by generative behaviors such as providing self-explanations or drawing concept maps. Both kinds of engagement exceed the benefits of Active or Passive engagement, marked by manipulating some parts of learning materials (e.g., verbatim note-taking or manipulating digital representations) and attentive behaviors (e.g., receiving information by viewing a lecture), respectively. For example, Chi et al. (2018), while describing a 5-year research study of ICAP framework implementation into schools' instruction, found better learning outcomes when students learned in the context of Constructive than Active activities.

Following the ICAP framework, which proposes that the more learning activities elicit cognitive engagement, the better the learning outcomes will be, current research proposes a unique opportunity to explore the effectiveness of learning with dynamic visualizations using the ICAP perspective. With this aim in mind, this study addresses two research questions: (1) What is the impact of learning with different multimedia visualizations (agent-based models compared with learning using other visual representations such as videos and animations) as part of computer simulation embedded design, on learning gains? (2) How are students who have different academic achievement levels affected by learning with different simulation visualizations?

Methods

Research Design

This research employed a within-group, pretest and posttest, time-series design using a quantitative approach.

Participants and Procedure

Participants were undergraduate nursing students at the University of Haifa in Israel (n = 97; 28 males, 69 females; mean age 22.4 ± 1.9). Between October 2016 and October 2017, participants completed online clinical simulations covering three topic areas in the following sequence: gastrointestinal disorders (using animations), endocrine disorders (using agent-based models' exploration), and mental health disorders (using video-based visualizations). To ensure alignment of complexity between the content of the three simulations, experienced lecturers in the university nursing department reviewed and validated the content. Students were required to complete all the simulations individually from their homes within 6 hours on predetermined days. Pretest and posttest evaluations were administered immediately before and after each simulation.

The study was conducted after approval by the University of Haifa ethics committee.

Data Collection Instruments

Computer-Based Simulations

The National League for Nursing (NLN, 2015) stated that "simulation can take many forms, including human patient simulation (using manikins and/or standardized patients), virtual and computer-based simulations." Herein, this study evaluated three online clinical simulations that were developed as part of a computer-based-simulation platform (The Cheryl Spencer Department of Nursing, 2013). The mental-health simulation incorporated video-based visualizations, the gastrointestinal module was designed using animated representations, and the endocrine simulation was based on exploration of agent-based visualizations. The knowledge components of all three simulations were explicitly decomposed from subcategories of knowledge and then gradually combined through authentic clinical scenarios. Consistent with the 2016 International Nursing Association for Clinical Simulation and Learning guidelines for simulation, the required elements of scenario design, fidelity types, and feedback were met (INACSL, 2016). These online interactive learning experiences were embedded in a learning management system that enables tracking, reporting, and delivering the Internet-based simulations that can be accessed from any computer at any time.

Video-Based Visualizations

The mental health simulation incorporated multiple case-based scenarios that were video-recorded and embedded as connectors of various domains of mental-health disorders such as depression and schizophrenia. For example, one of the video-based scenarios involved an adolescent with a sudden change in personality and behavior. While observing these scenarios, students were asked to make decisions about the patient's physical and mental conditions, to develop a care plan, and to educate the patient and the patient's family about pharmacology treatment. Videos also represented different nurse−patient interactions; here, students were asked to evaluate the quality of the nurse's assessment and interventions.

Animation-Based Visualizations

The gastrointestinal module incorporated animated media that were designed using VYOND technology (https://www.vyond.com). This technology enabled the author to create animated case-based scenarios of nurse−patient interactions and visualizations of human anatomy and physiology. For example, an animated interaction depicted a patient who suffers from pain in the upper stomach (gallstones). Students were asked to assess the quality and intensity of the pain, to observe physical assessment and, following the unfolded animated scenario, to recommend appropriate evaluation tests, differential diagnosis, and possible treatments (Figure 1A). In addition, the animation media were used to represent interactively the gastrointestinal anatomy and physiology to explain patient symptoms.

ABM-Based Visualizations

The endocrine simulation incorporated agent-based models constructed using the NetLogo modeling platform (Wilensky, 1999) that were evaluated by the author in previous studies (e.g., Dubovi, Dagan, Mazbar, Nassar & Levy, 2018). The endocrine module enabled students to solve clinical problems in relation to diabetes mellitus while exploring and manipulating the models. Two central representations were used: (1) visualization of cells, organelles, and molecules related to blood glucose regulation (i.e., pancreas cells, muscle cell, and liver cell); and (2) plots and monitors showing overall levels of glucose and different medications within the blood system and other relevant body parts (Fig. 1B). Each cell model includes the main organelles and molecules that participate in the metabolic processes and the insulin mechanisms that maintain blood glucose equilibrium. The models are used to demonstrate the effects of various activities and diets on both healthy and diabetes type 1 or diabetes type 2 body functioning. Participants could add different types and doses of medications, manipulate multiple characteristics and habits (such as fasting or sport activities), and observe the subsequent body reactions. The use of multiscale models enabled participants to zoom in on each type of cell separately or to zoom out to view how the different types of cells work synchronously for a more comprehensive exploration of glucose blood regulation.

Clinical Reasoning Evaluation Tool

The Clinical Reasoning Evaluation (CRE) tool was developed by the author to assess students' clinical reasoning related to the following clinical topics: mental health (10 items related to mood disorders and psychotic disorders), gastrointestinal (10 items related to biliary and gall bladder

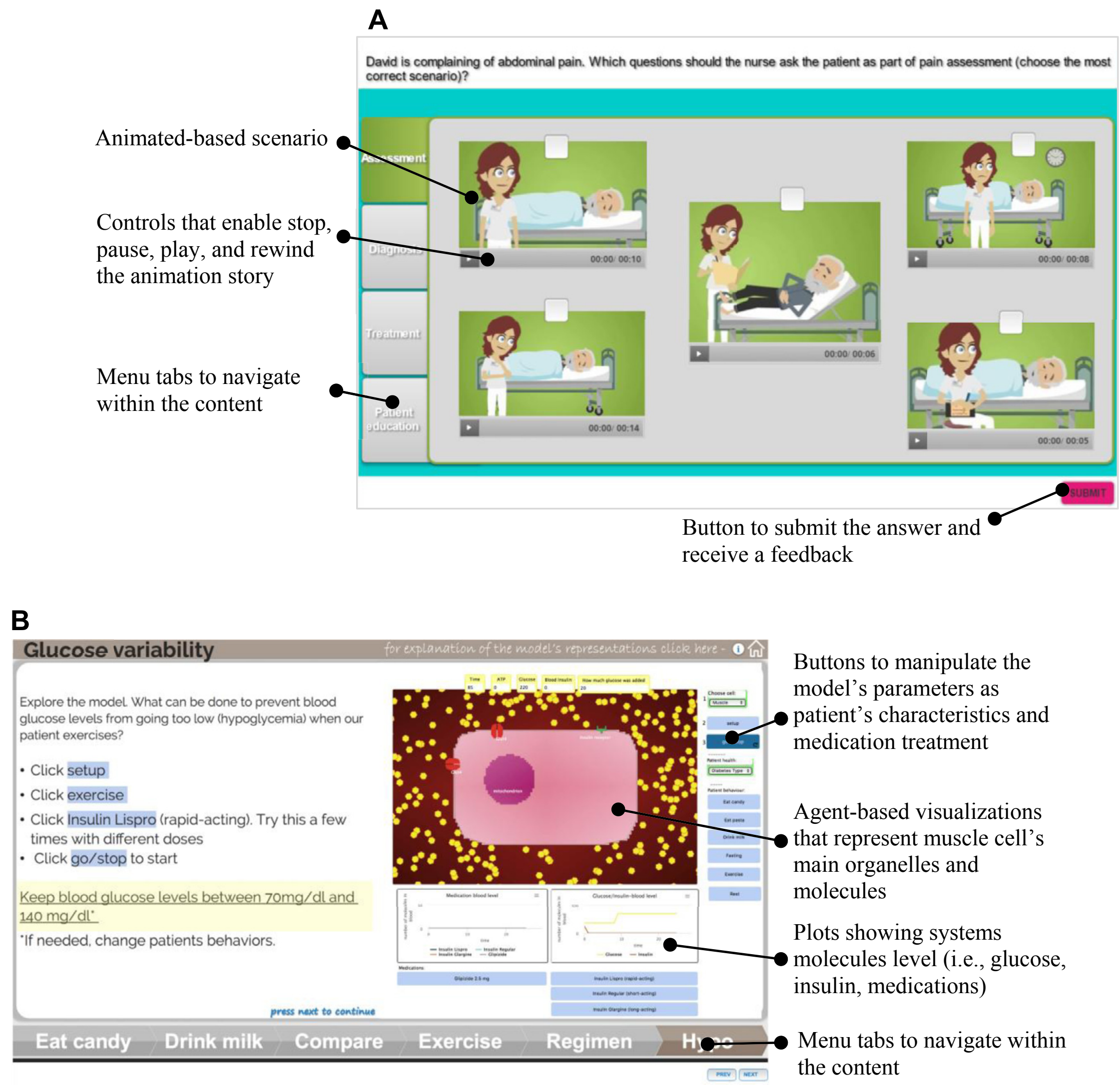

Figure 1 Screenshots of endocrine and gastrointestinal online simulations. (A) Gastrointestinal simulation, designed using animations to represent clinical scenarios and human anatomy and physiology. Scaffolds and feedback were provided for knowledge construction. (B) Endocrine simulation, incorporating exploration of agent-based visualizations. The model represents different cell types, plots to follow the system's changes, and buttons to explore. Various learning activities guided students' experimentation with the model.

disorders), and endocrine (10 items related to diabetes mellitus diagnosis and treatment). CRE items are multiple-choice and based on licensing examinations for the Registered Nurses Department of the Israeli Nursing Administration. The author also adopted items from a questionnaire developed and validated by Beck et al. (2015) to evaluate procedural knowledge related to diabetes mellitus. In addition, the items were reviewed by experienced lecturers in the university nursing department to ensure appropriate alignment of context and content and a suitable level of expertise. The tool incorporates questions according to the Five Rights of Clinical Reasoning model (the right cues, the right action, the right patients, the right time, and the right reason) proposed by Levett-Jones et al. (2010). Analysis of the CRE tool using Cronbach's alpha yielded a good internal consistency score of 0.68.

Statistical Analysis

Students' responses to items on the CRE were coded as correct or incorrect, and the total score was calculated as the percentage of correct answers. The pretest and posttest results, including the overall score for the simulation clinical topic and its domains, were analyzed with descriptive statistics (mean, SD) and compared using a paired *t*-test.

To compare the simulations, gain scores for each participant were calculated following each of the clinical simulation as (posttest score) − (pretest score). Interaction effects between the simulation instructional approaches were evaluated using repeated-measures ANOVAs. Students' academic achievement level was based on university-course examination scores, which were obtained from the university database. Each student's achievement was assessed with a standard score (Z score). The formula for calculating the standard score is $Z = (X - M)/SD$, where X represents the score of the individual student, M represents the mean score of all students in the same group, and SD represents the standard deviation of scores in the group (Cheng, Lam, & Chan, 2008).

Results

Results of the pretest and posttest scores are presented in Table, arranged by clinical topic and visualization type. The total posttest scores across all topics are significantly higher than the pretest scores, with large effect sizes of Cohen's *d* (Cohen, 1988). Pretest scores for the three knowledge questionnaires were comparable for the three groups, showing no significant differences ($F(1,96) = 0.215$, $p = .644$).

To compare the learning with the three simulations, which incorporated different visualizations, learning gains were calculated for each clinical simulation separately (see Table). Two-way, repeated-measures ANOVAs with a Greenhouse-Geisser correction revealed a significant interaction effect of visualization type on learning gains ($F(1, 96) = 14.536$, $p < .001$), with a partial $\eta^2 = 0.132$ (medium effect size). Bonferroni post hoc tests showed that the learning gain was significantly higher only for the endocrine clinical simulation, whose design was based on ABM exploration, compared with simulations that incorporated only a video- or animation-based technology ($p < .01$).

To evaluate the right fit between learner characteristics and visualization type, learning gains were calculated separately for high and low achievers for each simulation. The statistical analysis revealed that for the endocrine simulation, low achievers obtained significantly higher learning gains than high achievers did (29 ± 21 vs. 19 ± 17; $t = 3.38$, $p < .05$). No significant differences between high and low achievers were found for the mental health (Table; $t = 0.89$, $p = .37$) and gastrointestinal (Table; $t = 0.37$, $p = .70$) simulations.

Discussion

Multimedia-based technology is becoming increasingly popular across a variety of clinical topics in simulation-based nursing education, with the aim to expand nursing students' traditional clinical experience. The current research compared learning with three different media technologies to identify the conditions under which different visualizations are most effective for learning. Overall, the results of this study suggest that learning with all three online multimedia-based simulations—video-, animation-, and agent-based visualizations—resulted in significantly higher posttest learning scores. These findings clearly support that online simulations promote clinical reasoning, which is consistent with nursing literature reports (Cant & Cooper, 2014; Durmaz, Dicle, Cakan, & Cakir, 2012).

Furthermore, to elaborate a better understanding of how it is possible to reinforce learning with computer-based simulations, this study evaluated the interplay between multimedia visualization types (video-, animation-, and agent-based), learner characteristics, and desired learning outcomes. The findings suggest that learning with agent-based visualizations resulted in significantly higher learning gains than learning with animation- or video-based visualizations. This finding can be explained by the

Table Comparisons of Pretest and Posttest CRE Scores and Learning Gains, by Clinical Topic and Visualization Type (n = 97)

			Statistical Tests		
Clinical Topic (Visualization Type)	Pretest Scores	Posttest Scores	Paired *t* Test	Effect Size, Cohen's d	Learning Gains
Mental-health disorders (video-based visualizations)					
Whole sample	61 ± 20	74 ± 15	−5.781†	0.565	13 ± 23
Low achiever (n = 48)	57 ± 21	72 ± 15	−4.315†	0.635	15 ± 22
High achiever (n = 49)	65 ± 18	75 ± 15	−3.461*	0.495	10 ± 23
Gastrointestinal disorders (animation-based visualizations)					
Whole sample	58 ± 27	68 ± 21	−3.127*	0.302	10 ± 32
Low achiever (n = 48)	57 ± 28	66 ± 22	−1.520	0.206	9 ± 39
High achiever (n = 49)	57 ± 27	69 ± 19	−3.078*	0.439	12 ± 25
Endocrine disorders (agent-based visualizations)					
Whole sample	62 ± 19	87 ± 10	−12.029†	1.210	25 ± 20
Low achiever (n = 48)	55 ± 19	84 ± 10	−8.911†	1.317	29 ± 21
High achiever (n = 49)	70 ± 16	89 ± 09	−8.166†	1.168	19 ± 17

Data are presented in percentage mean ± SD, range 0 to 100.
Learning gain was computed to compensate for differences in prior knowledge (posttest—pretest).
Note. CRE = Clinical Reasoning Evaluation.
* $p < .01$.
† $p < .001$.

ICAP framework, which proposes that the more the students are cognitively engaged with their instructional materials, the better their learning outcomes (Chi et al., 2018; Chi & Wylie, 2014). Learners' engagement with instructional materials can be operationalized as the active mode if some form of overt motoric action or physical manipulation is taking place. Video- and animation-based visualizations provide storyline representations that offer a limited set of manipulations, such as pausing and rewinding, and represent a narrative from a third-person perspective (Chi, Roy, & Hausmann, 2008). Agent-based representations, by contrast, can also be manipulated, in addition to the third-person perspective, from the individual agent's action (a first-person perspective), such as by controlling molecule interactions with cell membranes and with other molecules while manipulating various patient characteristics and parameters. This interactivity—the ability to simulate different health conditions and to run experiments while asking "what-if" questions—facilitates students' construction of their own understandings and ideas, which is operationalized by the ICAP framework as a mode that is superior to the active mode, known as the constructive mode (Dickes et al., 2016; Russ, Scherr, Hammer, & Mikeska, 2008). Cognitively, the various manipulative and experimentation actions not only direct attention to what is being manipulated, which in turn activates prior knowledge, but also facilitate generation of new inferences and ideas. Furthermore, this activation and generative process allows new information to be linked to and stored with prior knowledge, thus making the new knowledge more complete, integrated, and strengthened, for easier retrieval.

This study aimed also to evaluate under which conditions different visualizations enhance learning. Interestingly, the current results show that when following learning with agent-based visualizations, low achievers made significantly higher learning gains than high achievers did. An explanation for this could be related to cognitive load theory (Ayres & Paas, 2007; Sweller, van Merrienboer, & Paas, 1998). Multimedia visualizations such as animations may impose greater cognitive processing demands because information is frequently transient—namely critical objects and their relationships disappear during the animation narrative—and thus learners are forced to process current information while trying to remember previous information. Agent-based visualizations, by contrast, offer high degrees of learner control, which allows learners to adapt parameters of the visualizations to their individual learning requirements—that is, to their own capacities as well as to the specific nature of the learning task—which in turn supports better management of cognitive resources (Homer & Plass, 2014). Consequently, learning with agent-based models, which is characterized by "low threshold" but "high ceiling" (simple but sufficiently robust for scientific learning), simplified mental processes that benefited more those learners who needed load-reducing strategies (Tissue & Wilensky, 2004).

Conclusion

This study is a first step toward understanding how different types of multimedia visualizations might affect nursing students' learning outcomes with computer-based simulations. More broadly, the findings suggest that level of learner control, level of interactivity with the visualizations, and the degree of cognitive proactivity influence learning outcomes by promoting active cognitive engagement and reducing cognitive load (Gee, 2007). Learners bring to any instructional situation a variety of experiences and prior knowledge, all of which can influence their learning process and therefore should be considered by nursing instructional designers. Future studies should further explore the differences in learning processes with different visualizations incorporating collaborative learning using qualitative and quantitative methods.

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