Enhancing learning through optimal sequencing of web-based and manikin simulators to teach shock physiology in the medical curriculum

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Submitted 2 July 2011; accepted in final form 20 September 2011

Cendan JC, Johnson TR. Enhancing learning through optimal sequencing of web-based and manikin simulators to teach shock physiology in the medical curriculum. Adv Physiol Educ 35: 402–407, 2011; doi:10.1152/advan.00061.2011.—The Association of American Medical Colleges has encouraged educators to investigate proper linkage of simulation experiences with medical curricula. The authors aimed to determine if student knowledge and satisfaction differed between participation in web-based and manikin simulations for learning shock physiology and treatment and to determine if a specific training sequencing had a differential effect on learning. All 40 second-year medical students participated in a randomized, counterbalanced study with two interventions: group 1 ($n = 20$) participated in a web-based simulation followed by a manikin simulation and group 2 ($n = 20$) participated in reverse order. Knowledge and attitudes were documented. Mixed-model ANOVA indicated a significant main effect of time ($F_{1.38} = 18.6, P < 0.001, \eta^2_p = 0.33$). Group 1 scored significantly higher on quiz 2 (81.5%) than on quiz 1 (74.3%, $t_{19} = 3.9, P = 0.001$), for an observed difference of 7.2% (95% confidence interval: 3.3, 11.0). Mean quiz scores of group 2 did not differ significantly (quiz 1: 77.0% and quiz 2: 79.7%). There was no significant main effect of group or a group by time interaction effect. Students rated the simulations as equally effective in teaching shock physiology ($P = 0.88$); however, the manikin simulation was regarded as more effective in teaching shock treatment ($P < 0.001$). Most students (73.7%) preferred the manikin simulation. The two simulations may be of similar efficacy for educating students on the physiology of shock; however, the data suggest improved learning when web-based simulation precedes manikin use. This finding warrants further study.

The University of Central Florida College of Medicine (UCF-CoM) is one of a number of new medical schools enrolling students in the first decade of the 21st century in the United States. As a consequence, UCF-CoM has had the opportunity to define all curricular components involved in medical education with the benefit of the collective experiences of other programs that have preceded us as well as an expectation to incorporate educational technologies even as courses were being delivered for the first time. The Association of American Medical Colleges (AAMC), through its Institute for Improving Medical Education, has challenged medical educators to scrutinize how and when novel educational technologies are to be included in the curriculum (1). The present study is an example of this curricular investigation. The drivers for the research included the institutional and curricular demand to understand the relative roles of the various technologies and their individual effects on student learning, the need to understand a process by which we may be able to objectively measure this effect, and the essential requirement to plan accordingly for anticipated student enrollment growth and subsequent resource pressures.

The physiology of the cardiovascular system is taught in several preclinical courses at UCF-CoM. Although there is some overlap, the first-year medical student is exposed to normal cardiovascular function, and abnormal states are addressed in the second year of school. The study activities occurred during the second-year cardiac and pulmonary pathophysiology module. The curriculum leadership has been keen to include clinical examples and simulations in a robust manner; however, in preparation for this activity, we found a lack of clear evidence as to which of the available simulation platforms would prove to be most useful for our students. As a secondary issue, we were also concerned about the ability to deliver the curricular technologies to our growing number of matriculated students. Currently, our plan is for steady growth in enrollment, with a first class sized at 40 students and growing thereafter by 20 students/yr, to a maximum class size of 120 students.

The advantages of simulation technologies have been widely reported, but a number of simulation platforms could be used to highlight the underlying physiology of shock; the medical educator may need to choose among them or, possibly, to use a combination when planning the educational agenda. The relative usefulness of two simulation technologies that address the topic of the abnormal cardiovascular function associated with the shock state were analyzed.

MATERIALS AND METHODS

Participants

Participants in this study included all 40 students enrolled in their second year of medical education at UCF-CoM. This student group consisted of 18 men (45%) and 22 women (55%) aged 20–34 yr. Participant consent was obtained after study approval by the Institutional Review Board of UCF.

Study Protocol

This study used a randomized, counterbalanced repeated-measures design in which all students participated in two educational interventions (Fig. 1). Students were randomly assigned to one of two training sequence groups using GraphPad software: 1) the “web-based, manikin” group of students (group 1; $n = 20$), who first participated in a web-based simulation and later crossed over to participate in a manikin simulation; and 2) the “manikin, web-based” group of students (group 2; $n = 20$), who first participated in a manikin simulation and later crossed over to participate in a web-based simulation.
Overview of Simulation Training Interventions

The web-based simulation was a computer-aided instruction that was accessible as an online textbook, which includes rich user-driven cardiovascular simulations that allow the manipulation and exploration of standard cardiovascular metrics (e.g., cardiac output and heart rate) in real time. This technology was made available in a beta-version by its developer, Dr. Craig Knoche, at http://www.physiosim.org/. The user experience with this educational device includes reading materials augmented by relevant rich interactive simulations. For example, in the section that deals with the cardiac pressure-volume (P-V) loop, the user is able to manipulate slider bars that affect venous caliber, venous compliance, and circulating blood volume with real-time correction and visualization of the P-V loop. The activities are guided with specific instructions for the student to highlight physiological responses.

The second technology was the SimMan 3G system (Laerdal Medical, Wappingers Falls, NY). This system uses a human-scale manikin with a rich underlying physiology simulation engine that responds to user inputs like fluids and medications. The student can observe the changes affected by their therapeutic decisions in both a monitor-type system as well as in some physical manifestation in the manikin; for example, a hypotensive manikin will have weak palpable pulses. This system requires supervision from an instructor and a technical assistant to interact with the controlling software.

Application of Interventions

Web-based training. Students were assigned to complete pages 16–25 of the online textbook. This section is entitled “cardiac performance” and includes simulation exercises in venous compliance, blood volume and volume replacement, sympathetic stimulation, cardiac contractility and medications that alter that state, as well as a very clearly articulated exercise that takes the student through simulated manipulations that specifically mimic neurogenic, hemorrhagic, septic, and cardiac shock. This 1-h activity culminates with a comprehensive cardiac performance simulation where the student can manipulate any of the factors and make observations to the system-wide effects. Students completed this training independently, without the presence of an instructor or other students.

Manikin training. Students were randomly placed into groups of five. Two groups, each with its own SimMan, were placed side by side with one instructor and a single technician to run the two simulators. These 10 students were then guided through the 4 scenarios (i.e., neurogenic, hemorrhagic, septic, and cardiac shock) using a script to minimize variation. Students were free to ask questions about management and evaluation, and these were answered by the instructor. While the students participated in this training in small groups, they did not collaborate to problem solve, as would be intended in a traditional team-based learning environment. The training was delivered in this manner due to the availability of only two manikins in the facility. Accordingly, this activity was repeated as four 1-h sessions to include all study participants. The same instructor facilitated all four training sessions.

Instrument Design

Two instruments were created for use in this study: a 30-item quiz consisting of multiple-choice questions to assess knowledge and a 10-item survey consisting of Likert-type rating scale items, a ranking item, and open-ended items to assess student perspectives of the simulation training experiences.

The quiz items (Fig. 2) were written by the first author and were specifically constructed for this study to address the training session objectives. The 30-item quiz was delivered online to all students via Questionmark Perception 4.4 at both times of assessment (Fig. 1). Students accessed and completed the quiz after each simulation intervention on desktop computers in our training center.

We designed and delivered an online user experience survey via SurveyMonkey. Students rated the extent to which each simulation was helpful for understanding 1) the physiology of shock and 2) the treatment of shock based on a five-point rating scale (i.e., where 1 = strongly disagree and 5 = strongly agree). Open-ended items allowed students to comment on 1) strengths and 2) weaknesses as well as suggestions for improvement of each simulation. Finally, students were asked to select their preference for simulation training environment and to rank order six distinct features of the environments according to level of importance (Fig. 3). The six features assessed were specifically presented due to their unique association with one of the two simulation training environments, i.e., the web-based environment was applied as a self-guided, independent learning tool that provided the ability to manipulate physiological scenarios and has the potential for 24-h accessibility, whereas the manikin environment was applied as a group learning tool that provided visual, tactile, and auditory impact while an instructor was present. To avoid any bias, the features were listed alphabetically in the survey ranking item.

Statistical Analysis and Data Expression

Statistical analyses of quantitative quiz and survey data were completed using IBM SPSS/PASW Statistics 18 (Chicago, IL). Descriptive data related to quizzes are reported as mean scores (expressed as percent correct) ± SD. Mixed-model ANOVA was conducted to examine the main effects of time and training sequence group and to assess whether a time by training sequence group interaction was present. Followup comparisons, where appropriate, were conducted using dependent t-tests. Survey rating scale data were treated as interval-level data; accordingly, mean comparisons between training sequence groups were conducted using independent t-tests. A significance level of 5% was used for all statistical tests. Qualitative survey responses were exported from SurveyMonkey for thematic content analysis.

RESULTS

Quiz: Student Learning

Group 1 (n = 20) obtained a mean score of 74.3% (SD 9.1%) on quiz 1 and a mean score of 81.5% (SD 8.8%) on quiz 2. Group 2 (n = 20) obtained a mean score of 77.0% (SD 10.220.33.5 on June 18, 2017 http://advan.physiology.org/ Downloaded from http://advan.physiology.org/ by 10.220.33.5 on June 18, 2017
5.4%) on quiz 1 and a mean score of 79.7% (SD 5.5%) on quiz 2 (Fig. 4).

Mixed-model ANOVA was conducted using time of assessment as a within-subjects, repeated-measures factor and training sequence group as a between-subjects factor. There was no significant main effect of training sequence group ($F_{1,38} = 0.04, P = 0.84$). There was, however, a significant main effect of time ($F_{1,38} = 18.6, P < 0.001, \eta^2_p = 0.33$). Post hoc

1. Sympathetic stimulation will lead to decreased venous compliance. Which cardiac performance factor will be directly affected?

- (A) Afterload
- (B) Contractility
- (C) Heart rate
- (D) Preload

2. Hemorrhage from a bullet wound in the femoral vein will cause hypotension through which mechanism?

- (A) Bradycardia
- (B) Decreased cardiac filling
- (C) Decreased peripheral arterial resistance
- (D) Reduction of cardiac contractility

3. Treatment for hemorrhagic shock can be initiated with

- (A) Blood transfusion
- (B) Metoprolol
- (C) Nitroglycerin
- (D) Saline bolus

4. During diastole the left ventricle fills with oxygenated blood. The pressure in the normal ventricle will

- (A) Decrease
- (B) Increase
- (C) Lead to isovolumetric contraction
- (D) Lead to isovolumetric relaxation

5. How does neurogenic shock affect cardiac function?

- (A) Decreases afterload
- (B) Decreases cardiac contractility
- (C) Enhances preload
- (D) Enhances venous compliance

Understanding and Treating Shock: Simulation Training User Satisfaction

Section III: Comparison of Simulation Training Resources

Which of the simulation training resources for understanding the physiology and treatment of shock do you prefer?

- Mannequin simulation
- Web-based simulation
- I do not have a preference

Place the following features of simulation training resources in order of importance to you, where a ranking of 1st represents the most important feature to you, and a ranking of 6th represents the least important feature to you. You may use each ranking only once (i.e., no ties).

- 24-hour accessibility to resource
- Ability to manipulate physiological scenarios of resource
- Group learning during use of resource
- Instructor accessibility during use of resource
- Self-guided, independent learning during use of resource
- Visual, tactile, and auditory impact associated with a simulated full-sized human body during use of resource

Fig. 2. Example quiz items.

Fig. 3. Example survey items.
Comparisons indicated that students in group 1 scored significantly higher on quiz 2 compared with their mean performance on quiz 1 ($t_{19} = 3.9$, $P = 0.001$), with an observed difference of 7.2% (95% confidence interval: 3.3, 11.0). Mean quiz scores of students in group 2 did not differ significantly across time of assessment ($t_{19} = 2.0$, $P = 0.06$). Finally, the interaction effect of training sequence group by time was not significant ($F_{1.38} = 3.9$, $P = 0.06$).

Survey: Student Feedback

Thirty-eight of forty students (95%) elected to complete the simulation user satisfaction survey after completion of quiz 2. Mean ratings (on a scale of 1–5) by students of each simulation environment indicated that the web-based and manikin simulations were similar in their usefulness to aid in understanding the physiology of shock (mean rating of the web-based simulation: 4.00 and mean rating of the manikin simulation: 4.03; $t_{74} = 0.15$, $P = 0.88$); however, the simulation environments were rated by students to be different in their usefulness to aid in understanding the treatment of shock (mean rating of the web-based simulation: 3.26 and mean rating of the manikin simulation: 4.45, $t_{74} = 5.6$, $P < 0.001$, observed difference: 1.18, 95% confidence interval: 0.76, 1.61).

Overall, the majority of students (73.7%) indicated that they preferred to participate in the manikin simulation for purposes of learning the physiology and treatment of shock (5.3% of students preferred the web-based simulation and 21.0% of students reported no preference). The students also specified strengths and weaknesses of both simulation environments and offered suggestions for improving the weaknesses; these qualitative data were examined for similar themes through content analysis. The leading strengths of the manikin simulation included the 1) presence of monitors that allowed for real-time visualization of physiology; 2) availability of a clinical team that afforded interactions with the instructor and peer group; 3) participation in an active, hands-on learning experience; and 4) engagement in a learning experience set in a realistic clinical context. The most frequently reported weaknesses and accompanying suggestions for improving the manikin simulation included 1) allowing more time for the training event and 2) allowing for student-directed exploration. The leading strengths of the web-based simulation included 1) interactive and dynamic graphic components and 2) content well suited for teaching the physiology of shock, in particular. The most frequently reported weaknesses and accompanying suggestions for improving the web-based simulation included 1) placement of the training activity earlier in the curriculum, 2) access to the simulation from home, and 3) inclusion of more treatment-related content.

Finally, students were asked to rank six features of simulation environments based on order of importance (using the first as the most important and the sixth as the least important). The number of students ranking each feature in each position was recorded by SurveyMonkey and subsequently exported for analysis. Table 1 shows the features in order of importance, as ranked by students.

**DISCUSSION**

Here, we describe a process that provides objective evidence informing considerations for the future use of these two novel technologies and their relative roles in shock education. From a methodological standpoint, however, the small class size limited our ability to be definitive with respect to subgroup analyses and, although random assignment was used to form probabilistically equivalent groups and thereby reduce the need for a baseline knowledge assessment, random assignment does not guarantee group equivalence. This may be evidenced by the differences in the SDs of the quiz scores between the two groups. Additional reasons for the exclusion of a baseline knowledge assessment were that 1) a learning effect was already possible because the quiz was delivered twice as a posttest measure and 2) the students move through the curriculum as an intact cohort and, thus, were presumed to have comparable knowledge before the training sessions.

We have identified that 1) sequencing the technologies such that the student is primed with the web-based experience before manikin simulation may enhance learning and 2) incorporating open-ended items on the user survey pointed to relative strengths and weaknesses of the technologies; however, 3) these were largely echoed by students’ responses to the rank list survey item. The latter two findings are of interest as the open-ended items are more time intensive to evaluate than the rank list item, with little additional information gained. In

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**Table 1. Student-ranked importance of simulation training features**

<table>
<thead>
<tr>
<th>Final Rank</th>
<th>Features of Simulation Training Resources</th>
<th>Total Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Instructor accessibility during use of resource</td>
<td>165</td>
</tr>
<tr>
<td>2</td>
<td>Ability to manipulate physiological scenarios of resource</td>
<td>165</td>
</tr>
<tr>
<td>3</td>
<td>Visual, tactile, and auditory impact associated with a simulated full-sized human body during use of resource</td>
<td>147</td>
</tr>
<tr>
<td>4</td>
<td>Self-guided, independent learning during use of resource</td>
<td>124</td>
</tr>
<tr>
<td>5</td>
<td>Group learning during use of resource</td>
<td>99</td>
</tr>
<tr>
<td>6</td>
<td>24-h accessibility to resource</td>
<td>98</td>
</tr>
</tbody>
</table>

Data were derived as follows: 1) first-place values were multiplied by 6, 2) second-place values were multiplied by 5, 3) third-place values were multiplied by 4, 4) fourth-place values were multiplied by 3, 5) fifth-place values were multiplied by 2, and 6) sixth-place values were multiplied by 1. Weighted values were then summed across each feature to yield a final score. As a result of this transformation, a tie occurred for the most important feature; this tie was resolved by number of original first-place rankings.
future studies, we will use rank lists primarily to garner user insight regarding the importance of simulation features, with the inclusion of one text box to allow for specific commentary. The student responses to this trial have persuaded us to consider a mechanism whereby we either allow more direct manikin control to the student or consider hosting the web-based sessions with faculty supervision in the future. The student responses pointed for a desire to control the simulation engine themselves but to have supervision available.

The two educational conditions evaluated were quite different from a resource standpoint. This particular issue was on full display when we considered the possibilities of charging the students with an online activity that they could perform at home with minimal cost compared with an activity that would require a significant material investment in the initial purchase cost of manikins, the cost associated with housing them, and having both faculty members and staff present to run the simulations. Additionally, the difficulty of navigating large numbers of students through simulations that require a limited resource can be dramatic as we consider the curricular footprint for such educational activities.

Any conclusion about the educational impact observed from these experiences must be couched in the context that, although the technical representation (i.e., fidelity) of the experience may be good or even excellent, the curricular construct and guidance available to the learner while engaged with the simulation were quite different. Conclusions drawn from this research encompass the entire curricular construct and include the simulation as a component. The two student experiences differed in that the web-based experience was an individual learning, user-centered experience (i.e., the student controlled progress), whereas the manikin-based simulation was a group learning experience guided by the instructor. Although the nature of the manikin-based intervention allowed for students to learn in a group setting, the faculty members observed that students directed their questions and comments specifically to the instructor rather than engaging with other students to solve the problem as a team. The benefits that are typically recognized as occurring with team-based learning were not likely achieved. Unguided, or minimally guided, approaches to simulation are attractive in the field of medical education because of the high instructional cost associated with medical experts. However, educational psychologists have recognized that human cognitive architecture and empirical educational evidence suggests that instructional approaches that emphasize guidance are more effective than minimally guided approaches (4).

There are numerous examples of simulations that, while excellent in their fidelity and representation of medical conditions, vary widely in the amount of guidance. Lasslo and colleagues (6) at the University of California (Davis, CA) provide a free web-based simulation of conditions affecting the eyes (http://cim.ucdavis.edu/EyeRelease/Interface/TopFrame.htm), which presents case vignettes and a simulation of relevant pathologies and has an exploratory component that provides minimal guidance and no direct feedback. The tool is excellent as an exploratory platform, but as a consequence, the student is able to configure combinations of pathology that would typically not occur simultaneously in a clinical setting. In a purely exploratory manner, it could cause confusion.

A similarly rich physiological platform developed by Kofranek and colleagues (5) (http://www.physiome.cz/atlas/index_en.html) provides an online well-described physiology model of the pulmonary, cardiac, and other systems in an educational construct that provides some interactive lectures as well as exploratory components. Again, some case vignettes are available to the user, but performance feedback is not directly available.

The balance between guidance and direct control of the physiological response warrants further investigation. While our students considered the accessibility of the instructor as the most important feature of the sessions, they longed to be in direct control of the technological interface. In addition to considering the use of the web-based and manikin simulations in combination, future studies could focus on enhancing instructor availability during web-based sessions or, conversely, allowing the students to directly interact with the SimMan 3G control system.

In an effort to understand why sequencing may be an important effect, we can also refer to the description of human cognitive architecture by Atkinson and Shiffrin (2). Long-term memory is now viewed as the central and dominant structure of human cognition (4). It is the long-term memory that allows us to rapidly draw upon previously learned material at a subconscious level, allowing us the latitude to respond automatically to circumstances and new inputs. New information, however, imparts a heavier processing cost and is managed in the working memory. This component of our neural infrastructure is notoriously limited in capacity and duration. These limitations are particularly applicable when considering new material that has not been learned. Taken in concert, “the advantage of guidance begins to recede only when the learners have sufficiently high prior knowledge to provide ‘internal’ guidance” (4). It is evident that some guidance and prior understanding allow the learner to engage new materials with maximal efficiency; there is no reason to think that learning from simulation would be immune from these limitations.

The finding that the web-based simulation, followed by the manikin simulation, may allow for greater knowledge improvement also fits the cognitive architecture model described above as well as the educational construct of sequencing as described by van Merriënboer et al. (7). The applicable idea is that novices learn complex tasks differently than they learn simple tasks. The initial experience with the web-based model may have served the purpose of allowing the students to develop a mental model or schema that allowed them to gain and transfer maximally to the manikin simulation (8). Although the educational goals in both were the same, the complexity of the systems was different enough that the educator may conceive of the web-based system as a task trainer, whereas the manikin, with its purposeful reality, may conceptually be more like whole task instruction (3). Whole task instruction as a first experience may have been too burdensome from a cognitive load standpoint, and, hence, the enhanced performance pattern seen in those who came with some degree of pretraining obtained on the web-based system.

In conclusion, the counterbalanced, repeated-measures design allowed comparison of the relative merits of each simulation platform as well as an investigation into the effect of sequencing. Our research suggests the use of the web-based technology as a primer to the manikin-based simulation. A preparatory web-based interactive simulation platform may serve to maximize the impact of a complex manikin-based simulation when teaching second-year medical students shock.
physiology and treatment. Additional research with larger class sizes is warranted.

The investigators approached the broader questions posed by the AAMC with relation to the adoption of novel educational technologies and have presented an educational psychology argument that may be useful in interpreting the results. AAMC guidelines compel educators to formally evaluate the cardinal questions of how, when, and in what setting to deliver novel medical educational technologies for maximal efficiency. New simulation activities will be similarly scrutinized as they are considered and added to our curriculum.

ACKNOWLEDGMENTS

The authors thank Craig Knoche for granting access to the web-based physiology simulation experience at physiosim.org.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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