High-fidelity patient simulators to expose undergraduate students to the clinical relevance of physiology concepts

David M. Harris,1 Christine Bellew,1 Zixi J. Cheng,2 Juan C. Cendán,1 and Jonathan D. Kibble1

1Department of Medical Education, University of Central Florida College of Medicine, Orlando, Florida; and 2Burnett School of Biomedical Sciences, University of Central Florida College of Medicine, Orlando, Florida

Submitted 19 May 2014; accepted in final form 1 August 2014

Physiology educators are often faced with the difficulty of showing students the clinical relevance of the science they are learning. This occurs at the healthcare professional level before clinical rotations with direct patient encounters. This challenge is likely even more prevalent during undergraduate training as students are years away from exposure to an actual healthcare setting. Physiology, which is arguably the foundation of clinical medicine, is a difficult subject for students of all levels to learn for various reasons, including the fact that it is conceptual and highly integrated (8). Therefore, finding avenues for undergraduate students, especially those in healthcare career tracks, to experience the clinical relevance of physiology “in action” may help student engagement, enthusiasm, and learning of physiology as well as help guide career choices.

The use of high-fidelity patient simulators (HFPSs) has expanded throughout medical, nursing, and allied health professions education in the last decades. These manikins can be programmed to represent pathological states and are used to teach clinical skills as well as clinical reasoning. First, the students are typically oriented either to the manikin or prebriefed about the specific case or scenario. This is followed by the 15- to 30-min simulation itself with a subsequent debrief about the experience (9). These HFPS experiences have been shown to improve learning and retention of physiology concepts in medical students (2, 5, 6). Interestingly, the use of HFPSs has also expanded into high school, college, and graduate schools in an effort to add problem-solving and critical thinking components to science classes (9). Gordon and Oriol (4) from the Harvard Summer Preclinical Institute have shown that student reflection reveals a deep satisfaction with the experience. Participation in these classes helped to improve confidence and reinforce humanism as well as providing clarity for future career choices (4). Although the idea of incorporating HFPSs within undergraduate courses appears beneficial on multiple levels, there are limited data regarding implementation and learning outcomes of the experience.

The purpose of this report is to share the data and reflections from a HFPS experience for biomedical students in our undergraduate program. The 2-h HFPS experience was part of an upper-level undergraduate course titled “Laboratory Virtual Simulations in Physiology,” which is a mixed-mode class consisting of laboratory modules and limited face-to-face lecture time. The HFPS experience was developed and facilitated by faculty members from the University Central Florida College of Medicine and School of Biomedical Sciences. The goals of this study were to determine the feasibility of the simulation activity, whether learning occurred in the activity, and whether students were engaged during the activity. A pretest and posttest were designed and given to participants to test knowledge and perceptions of teamwork and communication skills. This study was reviewed and exempted by the Institutional Review Board of the University of Central Florida, and students participated with informed consent.

Design of the Activity

A total of 34 undergraduate students participated in the HFPS session, and all activities were done within the Simulation Center at the University of Central Florida College of Medicine. The outline of the eight activities is shown in Fig. 1 and described as follows.

Pretest (~10 min). The pretest consisted of five physiology questions targeting relevant cardiovascular and pulmonary physiology concepts (see the Appendices) and five team process questions selected from the TeamSTEPPS curriculum (Table 1). Students had already had previous laboratory modules related to the simulation activities including cardiovascular hemodynamics and spirometry.

Introduction (~20 min). The introduction included an introduction to the faculty members and a quick briefing on the capabilities of the manikin, the physical setting of the room, and how the vital signs were displayed on a bedside monitor. At this point, the general approach to a patient as well as the logistics of the session were discussed. For each of the manikins, there were five to six students participating in the HFPS experience and five to six students observing and monitoring teamwork and communication skills. Observers were informed that they were expected to comment on teamwork dynamics during the debriefing process.

Simulation case 1 (15 min). The first case was a preprogrammed acute asthma case available on the SimMan 3G (Laerdal Medical). The simulated patient had tachypnea, decreasing O2 saturation, tachycardia, and hypotension. The manikin slowly decompensated as the case continued over 10 min, and faculty members facilitated students in noting changes in the patient’s condition. Through the case, the faculty members prompted students about what aspects of basic physiology might be pertinent in the clinical case presented. The manikin was saved by proper treatment by faculty members in every case to avoid any issues regarding death of the “patient.” However, students were asked to come up with the basic physiology concept(s) to treat the patient.

Simulation case 1 debrief (25 min). In the debriefing session, the abnormal vital signs and whether the patient had a breathing or circulation problem based on the vital signs were...
Discussion. Next, there was a discussion on the case’s relation to basic physiology concepts such as the clinical relevance of the oxyhemoglobin dissociation curve. Additionally, students were asked to predict pulmonary function tests on the patient from the case. This section ended by allowing observers to discuss their view of the communication within the participating team.

Role switch. Observers and participants switch roles.

Simulation case 2 (15 min). This was a hemorrhagic shock case, which was preprogrammed in the SimMan 3G. Students were presented with a patient that had tachycardia, hypotension, tachypnea, and normalized O$_2$ saturation. Similar to the first case, the manikin decompensated slowly over 10 min to facilitate discussion of the changing clinical condition, and every patient was saved by proper treatment. Faculty members aided by prompting students about topics such as preload, venous return, and stroke volume.

Simulation case 2 debrief (25 min). During the final debriefing session, the abnormal vital signs and whether the patient had a breathing or circulation problem were again addressed. The relationship of the relevant basic physiology concepts, such as preload, stroke volume, and cardiac output, were discussed to promote understanding of the vital signs associated with hemorrhagic shock. The hemodynamic version of Ohm’s law (mean arterial pressure = cardiac output × systemic vascular resistance) was applied and related to the observed hypotension and tachycardia. The activity concluded by allowing the second set of observers to discuss their views of the communication within the participating team.

Posttest (10 min). A posttest identical to the pretest was given to assess the learning of medical physiology concepts and any changes to the perception of the importance of communication.

Evaluation of the Study

The pretest and posttest were intended to determine if undergraduate students could learn basic physiology concepts from the HFPS. The questions were therefore developed with the intention of relating basic physiology concepts to clinical medicine and were single best answer multiple-choice questions written with clinical vignettes (see the APPENDIX). Eighteen of thirty-four students successfully completed both the pretest and posttest. Twelve students arrived 5–10 min late and were allowed to take only the posttest. Four students were excluded from the study because of unclear marking of answers. Figure 2 shows the significant increase in class average between the pretests (1.72 ± 0.96) and posttests (2.61 ± 1.09, n = 18, $P < 0.005$ by paired Student’s t-test) of students who took both.

The five teamwork and communication questions on the pretest and posttest were modified from the validated TeamSTEPPS survey (http://teamstepps.ahrq.gov/). A Likert-like scale from 1 to 5, where 1 = strong disagreement to the statement, 2 = disagreement, 3 = neutrality, 4 = agreement, or 5 = strong agreement with the statement, was used on these questions. There was a significant increase in agreement on two of the five questions (Table 1). These data suggest that students may gain an appreciation of the importance of the teamwork and communication skills presented in the statements after the simulation activities.

Table 1. Pretest and posttest scores on the five TeamSTEPPS questions

<table>
<thead>
<tr>
<th>Statement</th>
<th>Pretest Average</th>
<th>Posttest Average</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>It is appropriate to continue to assert a concern about patient safety until you are certain that it has been heard.</td>
<td>4.33 ± 1.03</td>
<td>4.89 ± 0.32*</td>
<td>0.008</td>
</tr>
<tr>
<td>It is important for leaders to share information with team members.</td>
<td>4.61 ± 0.98</td>
<td>4.83 ± 0.38</td>
<td>0.260</td>
</tr>
<tr>
<td>Individuals who are not part of the direct medical care team should be encouraged to report changes in patient status.</td>
<td>3.72 ± 1.23</td>
<td>4.50 ± 0.79*</td>
<td>0.009</td>
</tr>
<tr>
<td>I prefer to work with team members who ask questions about information I provide.</td>
<td>4.33 ± 1.03</td>
<td>4.72 ± 0.57</td>
<td>0.110</td>
</tr>
<tr>
<td>Poor communication is the most common cause of reported errors.</td>
<td>4.44 ± 0.98</td>
<td>4.61 ± 0.50</td>
<td>0.381</td>
</tr>
</tbody>
</table>

Values are students’ mean averages ± SD; n = 18 students total. $P$ values were calculated using a paired t-test. *Significance.
Learning effect of the activity. There was an increase on the posttest versus the pretest as the mean went from $1.72 \pm 0.96$ to $2.61 \pm 1.09$. Cohen’s $d$ calculation was 0.87, which suggests a large learning effect. The increase in score is consistent with a HFPS activity with first-year medical students in which the pretest class average increased from 42% to ~63% correct on the posttest (6). Although these scores may seem minimal, it should be recognized that, in both cases, students were not prompted to the content within the cases nor were they given material to prepare. Another aspect that may compound the scores is the fact that the questions were worded as clinical vignettes and represent a different style of question than undergraduate students normally answer. Regardless, the data suggest a short-term learning effect from this activity. Future studies are needed to address whether long-term retention occurs with undergraduate students after simulation activities, which has been observed in medical students (3).

The validated TeamSTEPPS questions were included to gauge student perceptions about some of the key areas within the TeamSTEPPS initiative. TeamSTEPPS was instrumented in healthcare settings in response to the Institute of Medicine’s To Err is Human report (7) and places priority on patient safety by working to improve communication in healthcare settings. Interestingly, 10 yr after the release of the report, there was little change in patient safety (1). Therefore, other approaches may be needed to address this, which includes potentially beginning development of communication skills at earlier stages. Since many of the students enrolled in this biomedical course plan to pursue healthcare careers in the future, this type of learning may help to provide a foundation on teamwork and communication earlier in their careers. Although there was agreement on all the statements provided, there was a significant increase in two of five statements, suggesting a firmer agreement to the statement. The fact that agreement was initially high is most likely a result of the survey design.

Faculty and student perceptions of the activity. All participating faculty members agreed that the students were heavily engaged and enthusiastic in this activity. The moments of discovery as students started to link their basic physiology knowledge to what was occurring in the patient were easily appreciated by the faculty members. After the session, almost every student walked out from the experience offering many “thank you” messages and handshakes. Student comments revealed their feelings of how the activity enhanced their learning of physiology. When a student was asked to name one thing that she learned from the HFPS activity, she commented “Integrating everything we learned in physiology and applying it in the real-world setting. I was also able to get a better understanding of the concepts covered by reviewing them.” Another student stated that participation in the HFPS “provided us students a hands on approach in which we can physically perceive the aspects of the concepts or terms we were learning, and allowed for a more real world simulation, rather than one just on Powerpoint or video.” Taken together, this suggests that HFPS activities provide a mechanism to apply undergraduate physiology.

Overall, it was felt that this activity was important in providing undergraduate biomedical students clinical relevance to the basic physiology that they have been learning in class. Future studies are necessary to assess longer-term learn-
ing retention. It was also an opportunity to share experiences that occur at the medical school and may provide guidance to students planning to pursue healthcare careers. With the increased need for healthcare workers because of the aging population, it is vital that we encourage and stimulate interest in undergraduate students to pursue health science careers. Activities like the one described in this article may be a mechanism to engage young learners and increase enthusiasm for pursuing careers in science, technology, engineering, and mathematics.

APPENDIX

Physiology Questions From the Pretest and Posttest

Question 1. Which values represent the normal heart rate and breathing rate of an adult?
A. Heart rate = 75 beats/min and breathing rate = 15 breaths/min
B. Heart rate = 120 beats/min and breathing rate = 18 breaths/min
C. Heart rate = 75 beats/min and breathing rate = 25 breaths/min
D. Heart rate = 135 beats/min and breathing rate = 6 breaths/min
E. Heart rate = 65 beats/min and breathing rate = 8 breaths/min
F. Heart rate = 110 beats/min and breathing rate = 12 breaths/min

Question 2. An unconscious patient is wheeled into the emergency room after complaining of chest pain to his wife. He is noted to have a heart attack (myocardial infarction). It is estimated that his cardiac output is 2.1 l/min (normal = 5.0 l/min). What changes in heart rate, respiratory rate, and blood pressure are most likely in this patient compared with normal?
A. Heart rate increased, respiration rate increased, and blood pressure increased
B. Heart rate decreased, respiration rate decreased, and blood pressure decreased
C. Heart rate increased, respiration rate increased, and blood pressure decreased
D. Heart rate decreased, respiration rate decreased, and blood pressure increased
E. Heart rate increased, respiration rate decreased, and blood pressure increased
F. Heart rate decreased, respiration rate increased, and blood pressure decreased

Question 3. If a person’s small airways constricted to half their normal size, what change would happen to airflow through the small airways if no other compensatory changes occurred?
A. Decreased by half
B. Increased by half
C. Decreased 4-fold
D. Increased 4-fold
E. Decreased 16-fold
F. Increased 16-fold

Question 4. A child is wheeled into the emergency room after getting stung by a bee. The child is having difficulty breathing and is wheezing because of this allergic reaction. What changes in spirometry values (residual volume, forced expiratory volume in 1 s (FEV1), and forced vital capacity (FVC)) are most likely to be present in this patient compared with normal?
A. Residual volume decreased, FEV1 decreased, and FVC decreased
B. Residual volume increased, FEV1 decreased, and FVC decreased
C. Residual volume decreased, FEV1 increased, and FVC increased
D. Residual volume increased, FEV1 increased, and FVC increased
E. Residual volume decreased, FEV1 increased, and FVC decreased
F. Residual volume increased, FEV1 increased, and FVC decreased

Question 5. A patient with difficulty breathing is admitted to the hospital where an arterial blood gas analysis is performed. The partial pressure of O2 in this sample is 60 mmHg. If pulse oximetry was done on this patient, what would be the most likely O2 saturation?
A. 25%
B. 40%
C. 75%
D. 90%
E. 100%

ACKNOWLEDGMENTS

The authors thank Jorge Nieves, Carolina Marchena, and Amanda Schuster for the technical help with this project.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS

Author contributions: D.M.H., Z.J.C., J.C.C., and J.D.K. conception and design of research; D.M.H., C.B., Z.J.C., and J.D.K. performed experiments; D.M.H. analyzed data; D.M.H. and J.D.K. interpreted results of experiments; D.M.H., C.B., and J.C.C. prepared figures; D.M.H., C.B., Z.J.C., J.C.C., and J.D.K. drafted manuscript; D.M.H. edited and revised manuscript; D.M.H. approved final version of manuscript.

REFERENCES

7. Institute of Medicine. To Err is Human: Building a Safer Health System (online). https://www.iom.edu~/~/media/Files/Report%20Files/1999/To%20Err%20is%20Human/To%20Err%20is%20Human%201999%20%20report%20brief.pdf [8 September 2014].