Using a high-fidelity patient simulator with first-year medical students to facilitate learning of cardiovascular function curves

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Harris DM, Ryan K, Rabuck C. Using a high-fidelity patient simulator with first-year medical students to facilitate learning of cardiovascular function curves. Adv Physiol Educ 36: 213–219, 2012; doi:10.1152/advan.00058.2012.—Students are relying on technology for learning more than ever, and educators need to adapt to facilitate student learning. High-fidelity patient simulators (HFPS) are usually reserved for the clinical years of medical education and are geared to improve clinical decision skills, teamwork, and patient safety. Finding ways to incorporate HFPS into preclinical medical education represents more of a challenge, and there is limited literature regarding its implementation. The main objective of this study was to implement a HFPS activity into a problem-based curriculum to enhance the learning of basic sciences. More specifically, the focus was to aid in student learning of cardiovascular function curves and help students develop heart failure treatment strategies based on basic cardiovascular physiology concepts. Pretests and posttests, along with student surveys, were used to determine student knowledge and perception of learning in two first-year medical school classes. There was an increase of 21% and 22% in the percentage of students achieving correct answers on a posttest compared with their pretest score. The median number of correct questions increased from pretest scores of 2 and 2.5 to posttest scores of 4 and 5 of a possible total of 6 in each respective year. Student survey data showed agreement that the activity aided in learning. This study suggests that a HFPS activity can be implemented during the preclinical years of medical education to address basic science concepts. Additionally, it suggests that student learning of cardiovascular function curves and heart failure strategies are facilitated.

The current generation of medical students has been raised in the technology age and has come to rely on computers and applications for the learning of complex material. Therefore, it has become the job of the educator to understand what technologies are available and, more importantly, how to implement these various technologies into the curriculum to achieve optimal learning results. In fact, the Association of American Medical Colleges (AAMC) has felt that the need for introducing technology into medical school curricula is so critical that it formed the AAMC Educational Technology Colloquium to identify educational technology advantages and suggest directions for future research (2). It was also reported from that colloquium that “little is established about precisely when to use it when it is employed” and that studies should determine how the use of technology can facilitate learning. Although incorporating technology, such as high-fidelity patient simulators (HFPS), into preclinical medical education cannot completely substitute for actual patient encounters, it appears to be one step closer to Flexner’s vision of benchside medical education (5).

Simulation has been used extensively in aviation and military training and is also rapidly becoming a part of medical education. The Liaison Committee on Medical Education has reported a 19% increase in computer simulation over 7 yr in a recent medical school questionnaire, yet the use and scope of simulation in medical education is not well known (3). According to an AAMC survey titled “Medical Simulation in Medical Education,” data from responding medical schools showed that simulation was used by 84% in year 1 and 91% in year 2 (3). This survey also showed that the majority of simulation in the preclinical years was dedicated to clinical skills, introduction to clinical medicine, and physical diagnosis. Despite physiology and pathophysiology forming a vital component in the foundation for basic science medical education, <40% of responding medical schools used simulation to teach these disciplines during the preclinical years (2). Furthermore, a review of simulation-based medical education research spanning 40 yr stated that a key feature of simulation-based medical education is curriculum integration and that research should be directed on how it can be integrated with other educational methods such as lecture and problem-based learning (14). Despite 40% of medical schools claiming that they use simulation to facilitate physiology learning, there are limited studies describing the incorporation of simulation activities into their preclinical curriculum.

Simulation also provides an avenue for active learning to occur and help meet the educational objectives and standards of the Liaison Committee on Medical Education. The benefits of active versus passive learning in medical education have been shown to create a deeper understanding of content material (1, 16), yet it has also been argued that medical education is slow to adapt its pedagogical methods (12). Active learning strategies replace the teacher-student relationship with a learner-learner relationship (9). Because of the various backgrounds of medical students, simulation scenarios allow for teaching between students of not only basic science but also patient safety, team communication, and other skills necessary for healthcare management and a clinical career. Furthermore, preclinical medical educators often have the difficulty of making students realize the clinical relevance of basic science concepts. The active learning associated with simulation activities provides a mechanism for preclinical medical students to

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connect basic science concepts to clinical management and decision making.

The present study describes the implementation of an HFPS activity into the problems-based curriculum at Drexel University College of Medicine and how an HFPS activity was used to facilitate student learning of basic cardiovascular (CV) physiology. A challenging physiology concept to first-year medical students was identified: CV function curves. The purpose of the HFPS activity was for students to actively learn how these graphs can be used to develop heart failure treatment strategies, providing relevance of basic science to clinical management. We collected pretest and posttest student data to determine whether this scenario helped students to learn CV physiology concepts. Furthermore, a survey was taken to gauge student perceptions of learning as well as overall satisfaction with the implementation. The overall goal of this study was to establish whether a simulation activity could be efficiently integrated into the physiology curriculum and whether a fundamental basic CV physiology concept could be learned by this method.

METHODS

The protocol for this study was approved by the Office of Regulatory Research Compliance of Drexel University College of Medicine under Exempt Category 4. The study was performed in the problem-based curriculum with first-year medical students at Drexel University College of Medicine in 2009 and 2010. Students within the problem-based curriculum met with their small groups (7–8 students/group) 3 times/wk for 3 h and had resource sessions during the week to address student-derived learning issues. Students were provided a resource session on CV function curves the day before the simulation activity. The topics of the resource session included defining mean systemic pressure (mean circulatory pressure) on the graph, which is the point at which the vascular function curve intersects with the x-axis. Additionally, students learned about the effects of preload, afterload, and contractility on the operating point, where the cardiac and vascular function curves intersect. The day after the resource session, the simulation activity was included within a small group session with a pretest and posttest to determine student learning of CV function curves within the case. The faculty facilitator of the small group was present for each small group in the simulation center. The settings used in the high-fidelity mannequin (SimMan 3G system, Laerdal Medical, Wappinger Falls, NY) were identical to the case patient they were discussing in group and are described in detail below. Additionally, there was a patient chart with reports of the history and laboratory/exam reports within the case. A description of what was included within the patient chart and human patient simulator (HPS) settings is included below.

Description of the Case Patient and HPS Settings

Patient chart. Mr. Patel is a 47-yr-old air traffic controller who presents to the emergency room with a 6- to 9-mo history of fatigue and dyspnea on minimal exertion. Previous medical history states that he had a myocardial infarction 5 yr ago.

HEMODYNAMICS. The following hemodynamics were provided:

- Right atrial pressure: 25 mmHg (normal: 2–10 mmHg)
- Right ventricular pressure: 70/28 mmHg (normal: 25–40/10 mmHg)
- Pulmonary artery pressure: 70/40 mmHg (normal: 25–40/15–20 mmHg)
- Pulmonary capillary wedge pressure: 35 mmHg (normal: 8–15 mmHg)
- Heart rate: 144 beats/min
- Cardiac output: 2.1 l/min (normal: 5–7 l/min)
- Systemic vascular resistance: 2,600 resistance units (normal: 800–1,200 resistance units)

ECHOCARDIOGRAM REPORT. The following electrocardiogram report was provided:

- Dilated left atrium, left ventricle, and right atrium
- Severe left ventricular global hypokinesis
- Ejection fraction of 30%
- Dilated cardiomyopathy

HPS Appearance and Monitor Settings

Initial appearance of the manikin was that he was diaphoretic, coughing loudly with crackles and lying on his back in a room set to look like an in-patient care room. The monitor upon entrance had the following initial parameters shown:

- ECG: sinus tachycardia
- Heart rate: 144 beats/min
- O2 saturation: 85%
- Arterial blood pressure: 100/70 mmHg
- Respiration rate: 28 breaths/min
- Cardiac output: 2.1 l/min

Students could place the oxygen mask properly on the manikin to provide supplemental O2 and, if done so, the O2 saturation would increase to 93% in all scenarios.

The timeline of the activity and how it was incorporated into the small group session is shown in Fig. 1A. Briefly, students entered their small group rooms and immediately took the pretest based on the CV function graph (Fig. 1B). After the pretest, students remained in their small groups and addressed learning issues from the previous session. The topic of the learning issues focused primarily on electrocardiography, regulation of blood pressure, and edema formation in their case patient. Students were then escorted to the Simulation Center, and,
upon entrance, an introduction to the Simulation Center and their “patient” was provided to the students along with the suggestion that they use their knowledge of CV function curves to treat the patient. Students were instructed to use information from patient laboratory reports, monitors, and clinical findings on the HPS to draw the following curves on the room’s whiteboard.

Normal CV function curve. Students were able to draw this curve based on typical normal values provided in the lecture and textbooks. The normal cardiac output is around 5 l/min and the normal right atrial pressure is around 2 mmHg for a male.

CV function curve from their HPS (based on their case patient). Students were able to draw this curve based on the cardiac output on the patient monitor, 2.1 l/min, and the right atrial pressure, 25 mmHg, included within the patient chart set immediately next to the manikin.

CV function curve based on their prediction of treatment. As students discussed treatment strategies, they would predict what changes would occur in their case patient’s CV curves and draw these on the whiteboard. After agreement, they would inject their chosen treatment(s), after which a CV function curve could be drawn by the students as posttreatment. Although they would not receive a new right atrial pressure at this time, they would see the improvement in cardiac output on the monitor and could predict a decrease in right atrial pressure.

Students were given three options for treatment (vasodilator, vasoconstrictor, and positive inotrope), which could be injected into the intravenous port in the manikin’s arm. Each “drug” was labeled with a specific radiofrequency, which was detected by the manikin. Therefore, although there was a staff member responsible for monitoring each manikin, the manikin responded to treatments independent of the simulator operator because of preprogramming of the scenario. Students were not responsible for proper doses of the drug; however, they were instructed to call out what drug they were administering as a patient safety precaution. Parameters changed within 5 min for the sake of time. Four possible drug treatment options were programmed into the manikin, and the monitor changes (occurring 5 min after the injection) are described below.

ADDITION OF VASODILATOR. The following changes occurred after the addition of the vasodilator:

- ECG: sinus tachycardia
- Heart rate: 125 beats/min

Table 1. Pretest and posttest scores from 2009 and 2010 from the problem-based curriculum and quiz averages of students in the 2010 lecture-based curriculum who participated in a large-room clinical case conference

<table>
<thead>
<tr>
<th>Question</th>
<th>2009 Pretest</th>
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<tr>
<td>1. Which letter represents the most likely operating point in a normal, healthy person? (Answer: D)</td>
<td>87</td>
<td>96*</td>
<td>96</td>
<td>98</td>
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<td>2. Which letter would represent the most likely operating point in a normal, healthy person after the administration of a drug that only caused vasoconstriction? (Answer: B)</td>
<td>29</td>
<td>43*</td>
<td>36</td>
<td>56*</td>
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<td>3. Which letter would represent the most likely operating point in a normal, healthy person that had increased sympathetic nervous system activation to his heart? (Answer: E)</td>
<td>56</td>
<td>66*</td>
<td>64</td>
<td>74*</td>
<td>N/A</td>
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<td>4. Which letter represents the most likely operating point for a person in severe congestive heart failure? (Answer: J)</td>
<td>35</td>
<td>78*</td>
<td>40</td>
<td>72*</td>
<td>N/A</td>
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<td>5. What would be the approximate mean systemic pressure (in mmHg) for the person in severe congestive heart failure in question 4? A: 4; B: 5; C: 7; D: 8; E: 12 (Answer: E)</td>
<td>16</td>
<td>57*</td>
<td>30</td>
<td>62*</td>
<td>N/A</td>
</tr>
<tr>
<td>6. Which letter represents the most likely operating point for a person in congestive heart failure following treatment with a diuretic and a positive inotrope? (Answer: G)</td>
<td>29</td>
<td>38*</td>
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How We Teach

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Data Analysis

Analysis for the knowledge questions shown in Table 1 was conducted using a paired-samples t-test comparing the pretest versus posttest.
the posttest. $P \leq 0.05$ was set to be significant. Survey questions were analyzed using a five-point Likert-like scale (where 1 = strongly disagree and 5 = strongly agree) to evaluate student satisfaction. A total of 116 students were included in this study (68 students in 2009 and 48 students in 2010). Sixteen student scores from 2010 were excluded from pretest and posttest scores due to improper administration of the tests.

RESULTS

Pretest and Posttest Scores

Since we were incorporating this activity into the curriculum for the first time, we wanted to determine whether the simulation activity aided student understanding of CV function curves. Therefore, six-question pretests and posttests were given to the students before and after the simulation activity (Table 1). Table 1 shows a statistically significant improvement in the percentage of students that received the correct answer on every question on the posttest except on question 1 in 2010, in which the initial score was 96%. The mean test score between the pretest and posttest also increased in 2009 (+21%) and 2010 (+22%). There was no significant difference in pretest or posttest scores between 2009 and 2010. To help determine whether students could learn from the simulation activity as effectively as another content delivery method, we compared scores to students ($n = 91$) from our lecture-based curriculum who participated in a large-room clinical case conference based on the simulation patient (included in the Supplemental Material).1 The same faculty member (D. M. Harris) gave the same lecture on CV function curves to both curricula as well as led the clinical case conference. Students in the lecture-based curriculum took a quiz, which contained question 2, the day after the clinical case conference. Posttest and quiz scores on question 2 were identical between the two groups, suggesting that the inclusion of a simulation activity may be as effective as a large-room clinical case conference to learn CV function curves.

Figure 2A shows that the median test score between pretests and posttests increased from 2 in both years to 4 (2009) and 5 (2010), respectively. Additionally, to assure us that the simulation activity did not negatively impact long-term understanding of CV function curves, question 2 was asked on the cumulative examination, which is given 4 mo after the conclusion of the physiology course. Figure 2B shows the improvement on the cumulative final compared with posttest scored in 2009 (43% to 75%) and 2010 (56% to 85%). The increase in median test scores indicated that the majority of students benefitted from the simulation activity. Therefore, further analysis was performed and revealed that of the 116 students in the 2 yr:

- 4 students had perfect scores on both the pretest and posttest
- 74 students improved by at least one question, of which 51 students improved by 2 or more questions
- 21 students had no change in score
- 17 students decreased their score

Survey Results

To address student feelings and perceptions about incorporating the simulation activity into the problem-based curriculum, a survey was used, and the averaged data are shown in Table 2. There were two students that did not provide survey data for 2009. Table 2 shows that the majority of students agreed or strongly agreed that the Simulation Center activity helped them to learn CV function curves, the role of cardiac mechanics in congestive heart failure treatment strategy, and the Frank-Starling law of the heart. Additionally, we included a “control” question (question 2) because this concept was not an objective of the Simulation Center activity to help assess the reliability of student responses and a comparably lower number of students agreed or strongly agreed with the statement. The majority of students strongly disagreed or disagreed with the statements about being overwhelmed, that the simulation activity was too long, and that they would have preferred to stay in their small groups. We also wanted to determine whether student feelings over a longer time period would change as the novelty of the exercise was less present. The end of the course evaluation, taken 4 mo after the conclusion of the course, is shown in Fig. 3. The majority of students in both years rated the simulation activity as good or excellent. Overall, these data suggest that students were in agreement that the simulation activity aided in their learning of basic physiology concepts.

1 Supplemental Material for this article is available at the Advances in Physiology Education website.
DISCUSSION

This report describes the implementation of a HFPS activity into a problem-based learning curriculum at Drexel University College of Medicine and how we used it to enhance understanding of a difficult basic science physiology concept: CV function curves. This study suggests that student learning of CV function curves and their utility in designing treatment strategies can be facilitated by HFPS. Additionally, the survey data suggest a favorable reaction from students regarding implementation of this activity into their curriculum and how they would like more to be included.

The present study provides data that shows that students in both 2009 and 2010 had similar percentage point increases in their averages between pretests and posttests (21% and 22%, respectively). Both pretest and posttest scores were increased similarly in 2010 compared with 2009 (+7.1% and +7.5%); however, there were no significant differences between the years ($P = 0.13$ and $P = 0.16$ by unpaired $t$-test). Student scores on the posttest after the simulation activity improved in both classes, but we cannot fully exclude the possibility that some student groups may have discussed CV function curves during the small group time preceding the simulation. Personal comments from the faculty facilitators stated that there was no discussion of CV function curves as the groups focused on their learning issues from the previous session. Most of the learning issues revolved around cardiac electrophysiology, baroreceptor physiology, and edema formation, as these were pertinent to the initial presentation of the case patient. However, the line between addressing subjects such as the Frank-Starling law of the heart, cardiac mechanics, and CV function curves and where the topics intersect is not totally clear. Additionally, since the problem-based learning style revolves around student-directed learning, the boundaries of discussion were set by each group and were not limited by faculty. It is important to note that regardless of what exactly was discussed during the small group session before the simulation activity, the improvement in posttest scores suggests that student learning occurred and consisted of both the small group session and the simulation activity. We cannot definitively exclude that the combination of these sessions is optimal for learning, and future studies are needed to address this matter.

One of the considerations of adding a new technology and content delivery method is to ensure that student learning is not affected negatively. We included question 2 (Table 1) on the final cumulative examination taken 4 mo after the course to assure us that students were able to understand CV function curves despite the inclusion of the simulation activity. While we cannot attribute the improvement in scores from the posttest to cumulative final to the inclusion of the simulation activity, these data coupled with the survey data suggest that students did not feel as though the simulation activity hampered their learning of CV function curves. A limitation in our study is that...

Table 2. Survey results

<table>
<thead>
<tr>
<th>Statement</th>
<th>Percentage of Students That Strongly Agreed or Agreed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The Simulation Center exercise helped me to learn cardiovascular function curves.</td>
<td>73</td>
</tr>
<tr>
<td>2. The Simulation Center exercise helped me to learn about the conduction system of the heart.</td>
<td>21</td>
</tr>
<tr>
<td>3. The Simulation Center exercise helped me to learn the role of cardiac mechanics in congestive heart failure treatment strategy.</td>
<td>84</td>
</tr>
<tr>
<td>4. I felt overwhelmed in the Simulation Center and was worried that I needed more skills.</td>
<td>64</td>
</tr>
<tr>
<td>5. The Simulation Center exercise was too long.</td>
<td>96</td>
</tr>
<tr>
<td>6. I would have preferred to remain in the small group to learn instead of using an exercise like the Simulation Center.</td>
<td>88</td>
</tr>
<tr>
<td>7. The Simulation Center exercise helped me to learn about the Frank-Starling law of the heart.</td>
<td>61</td>
</tr>
<tr>
<td>8. I would like to see more use of the Simulation Center in future cases.</td>
<td>87</td>
</tr>
</tbody>
</table>

Statements were scored based on the following scale: 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree.

Fig. 3. Student ratings of the simulation activity. End of course student ratings, ranging from excellent to poor, are shown for 2009 ($n = 68$ students) and 2010 ($n = 48$ students).
all students from the problem-based curriculum participated in the simulation activity for comparability reasons. Before researchers can analyze if students learn basic science concepts better by HFPS activities compared with other content delivery methods, it must be shown that HFPS can be implemented without detracting from student learning. We attempted to address this by including question 2 from the posttest on a quiz given to students in our lecture-based curriculum who participated in a clinical case conference (based on the simulation patient) instead of a simulation activity. The mean scores on question 2 were identical between the two groups, suggesting that the simulation activity may be as effective as a clinical case conference in the learning of CV function curves. However, the fact that students within the lecture-based curriculum took a graded quiz the day after the simulation activity may be a factor in their scoring. Additionally, the physiology in the lecture-based curriculum is integrated with other courses, such as anatomy, biochemistry, immunology, etc. Although it is highly unlikely those classes played a role in student learning of CV function curves, it cannot be ruled out. More research is needed to determine whether HFPS aids student learning better than widely used and accepted methods such as lecture, case conferences, or workshops. Ongoing studies are being performed to determine whether HFPS can improve student learning more effectively than other established content delivery methods.

Other studies have previously used clinical cases being brought “to life” by HFPS and have demonstrated improved student knowledge and perception in cardiac physiology. A study by Gordon et al. (8) was one of the first to show that preclinical medical students that participated in a tutorial session and a simulation activity regarding a myocardial infarction case scored ~18% better than medical students who only had the tutorial session. This improvement in test score was maintained at 1 yr. Although our study was limited to students only participating in a simulation activity, it is interesting that the percentage point increase in our posttest after the simulation activity is similar to the increase observed in simulation participants in the aforementioned study (~20%). Another study by Euliano (4) used a HFPS to teach the clinical relevance of Starling curves and analyzed student responses to an exam/survey and determined that performance improved on most questions. This study also included “control” questions on the cardiac cycle and excitation-contraction coupling that were not directly taught by the HFPS activity, and they observed increased student confidence in understanding those concepts at a significant level. However, there was a remarkable decrease in the test statistic, less than a quarter compared with other questions that were related to their HFPS activity. In fact, we also included a control question (question 2 in the survey) on the conduction system, which was not a focus of the simulation activity. We observed a similar result in which 21% of students agreed or strongly agreed that the HFPS had actually helped them understand the cardiac conduction system despite of the fact that this was not an objective of the activity. However, the percentage of students agreeing with the control statement was considerably lower than those statements concerning CV function curves (73%), cardiac mechanics (84%), and the Frank-Starling mechanism (61%), which were the objectives of the exercise, suggesting that students completed the survey with genuine responses. These data are consistent with the data acquired by Euliano (4). Future studies need to include multiple control questions to further dissociate this phenomenon. In accordance with the above studies, we also observed an improvement in student performance on every knowledge question.

An important aspect of simulation activities that was not included within our implementation and study was the formal debriefing process. Debriefing has been shown to be one of the critical processes needed for simulation and its effects on team building, which has been extensively studied by Salas (18). However, since the problem-based curriculum is student directed, we chose to allow students to discuss their experience within the small groups. Although a faculty facilitator was present in the small groups, they were not required to be content experts in the CV physiology field. Student satisfaction data and performance on the test questions did not indicate that this was a problem in the present study. However, the addition of a debrief could be included to further improve other important aspects, such as patient safety and communication skills.

When we reviewed the literature regarding simulation, implementation into curricula has arguably been best studied within the nursing education field (6, 7, 11). The common concepts addressed within the curricula via simulation include developing assessment, communication, and critical thinking/clinical reasoning skills along with therapeutic interventions (19). Our present study also included assessment of the patient and vital signs to identify congestive heart failure. Critical thinking and clinical reasoning skills were necessary to eventually formulate a treatment strategy for the patient. The survey results in our study indicated that the students agreed strongly that the exercise increased their ability to develop a treatment strategy. This may be due to the active learning that occurs with simulation, which results in augmented engagement between students. The excitement and tension that comes from analyzing and treating one of their first “patients” most likely puts them in a “high activation” state ideal for learning (17) as opposed to lectures, which many students find less engaging.

The most beneficial aspects of implementing simulation into curricula may be best reflected by student perceptions of the activity. Developing confidence is a key factor for students, and it has been noted that “only when nursing students have confidence in their own abilities are they able to shift focus to the needs of their patients” (13). Medical students most likely fall into this same sense of self-confidence. A study by Partin et al. (15) performed content analysis to identify themes in their students’ reflections of simulation experiences in obstetrics. They were able to identify three major themes: a non-threatening learning environment, enhancement of learning, and feeling of being prepared for practice. The Euliano study (4), as described above, also showed that student confidence improved, and the authors attributed this to increased interest and confidence gained during the HFPS activity. Another study (10) using a HFPS exercise with second-year preclinical medical students taking pharmacology showed an improvement in student toxicology knowledge and self-confidence. They noted an increase from 60% to 71% on a posttest that analyzed different pharmacology knowledge questions along with an increase in student confidence using a mean confidence questionnaire. Our survey data also indicated that students had a positive feeling toward the learning of CV function curves, which were the focus of our simulation activity. Although we
did not directly address student confidence, our survey data showed that the majority of students did not feel overwhelmed or worried about needing more skills after the Simulation Center activity (question 4). Developing confidence, teamwork skills, patient safety, and critical thinking skills may most likely be the key elements to be learned from HFPS during the preclinical years of medical education and separate this from simply “playing a doctor.” Although many of these aspects have been examined in the clinical training years, there are limited studies regarding these in the preclinical years of medical education.

Although there appears to be benefits of adding an active learning component such as a HFPS activity to a curriculum, more research needs to be done to find the most optimal application in the preclinical years. HFPS is costly in financial terms and in curricular time as it takes hours to rotate small groups of students through the Simulation Center. It takes a great deal of planning and cooperation in designing the scenario, programming the manikin, and planning the logistics of time and student movement in the Simulation Center. Additionally, before researchers can analyze if students learn basic science concepts better by HFPS activities compared with other content delivery methods, it must be shown that HFPS can be implemented without detracting from student learning. This leads to another drawback of HFPS, which is faculty recruitment and development. It can be difficult to get a “buy-in” from faculty members and the administration without showing that student performance is not affected by implementation.

In conclusion, this study explains how we implemented a HFPS activity into the problem-based learning curriculum at Drexel University College of Medicine. A challenge of medical school educators is to provide the clinical relevance of basic science concepts. The data suggest that HFPS may be a valuable tool to potentially apply knowledge regarding CV function curves to the development of heart failure treatment strategies and therapeutics. Survey data indicate that students perceived that they can learn basic physiology concepts using HFPS and that they would like to see more use of simulation within the curriculum. The present study suggests that a basic science concept can be learned by incorporating a HFPS activity and is comparable with another educational method. Simulation has also been used as a platform in nursing programs and graduate medical education to teach teamwork skills, patient safety, and interdisciplinary training. Medical institutions have been asked to include these skills into their undergraduate curricula, although there is a limited amount of time for basic sciences and these life-long learning assets. The inclusion of HFPS in the preclinical years may provide an avenue to teach these skills early in medical education without detracting from the learning of physiology.

DISCLOSURES

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

AUTHOR CONTRIBUTIONS

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

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