2015, 1–6, Early Online MEDICAL TEACHER

# A randomized controlled trial of high-fidelity simulation versus lecture-based education in preclinical medical students*

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## Abstract

**Purpose**: The purpose of this study was to compare the efficacy of simulation versus lecture-based education among preclinical medical students.

**Methods**: Twenty medical students participated in this randomized, controlled crossover study. Students were randomized to four groups. Each group received two simulations and two lectures covering four different topics. Students were administered a pre-test, post-test and delayed post-test. The mean percentage of questions answered correctly on each test was calculated. The mean of each student's change in score across the three tests was used to compare simulation- versus lecture-based education.

**Results**: Students in both the simulation and lecture groups demonstrated improvement between the pre-test and post-test ($p<0.05$). Students in the simulation group demonstrated improvement between the immediate post-test and delayed post-test ($p<0.05$), while students in the lecture group did not demonstrate improvement ($p>0.05$). When comparing interventions, the change in score between the pre-test and post-test was similar among both the groups ($p>0.05$). The change in score between the post-test and delayed post-test was greater in the simulation group ($p<0.05$).

**Conclusions**: High-fidelity simulation may serve as a viable didactic platform for preclinical medical education. Our study demonstrated equivalent immediate knowledge gain and superior long-term knowledge retention in comparison to lectures.

## Introduction

The core of "preclinical" (traditionally the first two years of medical school prior to initiation of clinical clerkships) medical teaching has classically consisted of lectures and textbooks. However, with advancements in technology more researchers are exploring the role of simulation in medical education (Hart & Harden 2000; Issenberg et al. 2005). Simulation modalities cover a broad spectrum including computers, standardized patients and high-fidelity patient simulators. Denson et al. first demonstrated the viability of simulation, using mannequins to teach anesthesia residents intubation skills, and over the past two decades, research in simulation-based education (SBE) has grown exponentially (Abrahamson et al. 1969; Denson & Abrahamson 1969; Issenberg et al. 2005). It has since expanded to fields, such as emergency medicine, pediatrics, radiology, trauma, nursing and medical education (Denson & Abrahamson 1969; Sica et al. 1999; Bond et al. 2004; Fiedor 2004; Gordon et al. 2006).

In the undergraduate medical education setting, the favorable perception of simulation is partly due to its creation of a low-stakes learning environment with real-time physiologic feedback in the absence of patient risk (Morgan et al. 2002; Ten Eyck et al. 2009). Simulation also allows for a unique learning experience where the student is actively engaged, receives performance measurements and is allowed to repetitively learn a task or concept related to the specific curriculum being taught (Issenberg et al. 2005; Okuda et al. 2009). Finally, the ability of SBE to induce emotional stresses and engage the learner in transfer-appropriate processing may also facilitate enhanced acquisition and retention of knowledge ascertained during a given simulator session (Weaver et al. 2010).

### Practice points

- Pathophysiology can be effectively taught to pre-clinical medical students by simulation and lecture.
- Simulation develops implicit memory which may facilitate long-term recall.
- Simulation may allow for the priming phenomenon to facilitate developing implicit memory during independent study.
- Simulation serves as a viable didactic platform and can be integrated into the pre-clinical setting.

The aforementioned aspects of simulation have made it a highly attractive learning modality, prompting researchers to evaluate whether simulation leads to enhanced learning in

*Material from this manuscript was presented as a poster at the UCLA Department of Medicine Research Day, October 2013, Los Angeles, CA.

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ISSN 0142-159X print/ISSN 1466-187X online/15/000001–6 © 2015 Informa UK Ltd.
DOI: 10.3109/0142159X.2015.1031734

undergraduate medical students in comparison to traditional lectures (Morris et al. 1977; Cahill et al. 1996; Sandi & Pinelo-Nava 2007). Despite the favorable aspects of simulation in comparison to traditional lectures, there is a paucity of objective research attempting to quantify the difference in knowledge acquisition between the two teaching methods, particularly in preclinical undergraduate medical education.

Studies in the current literature that directly compare SBE to lecture-based education use samples drawn from populations composed of residents or third- and fourth-year medical students. These studies focus primarily on teaching clinical concepts, such as management of shock, chest pain or dyspnea, while assessing outcomes including history-taking, physical exam and the execution of critical actions, such as intubation or defibrillation (Gordon et al. 2006; Steadman et al. 2006; Schwartz et al. 2007; Bassily-Marcus et al. 2010; McCoy et al. 2011). Many of these outcomes are assessed real-time, with occasional use of multiple choice post-tests (Gordon et al. 2006; Steadman et al. 2006; McCoy et al. 2011).

Studies comparing SBE to lecture-based education in pre-clinical medical students are few in number. To date, only two such studies exist, focusing on the pathophysiology of shock and autonomic pharmacology, subjects better suited for a pre-clinical population. Both of these studies used multiple choice post-tests, and neither of these studies demonstrated a statistically significant difference between the two learning modalities with respect to knowledge acquisition or long-term retention (Kasturi et al. 2009; Wong et al. 2007). Although, the initial studies attempting to objectively compare SBE to lectures have shown no significant difference, these studies only taught and analyzed one concept, whether that was the pathophysiology of shock or autonomic pharmacology (Kasturi et al. 2009; Wong et al. 2007).

The purpose of our study was to address this question in a broader setting using four unrelated pre-clinical topics taught by both simulation and lecture, in a randomized, controlled, crossover format. In addition, we sought to examine both immediate knowledge gain and long-term knowledge retention. Our hypothesis was that second-year medical students who participated in a simulation-based session would demonstrate increased knowledge acquisition and retention of the subject material when compared to students in the corresponding lecture-based session.

## Materials and methods

### Population and setting

Second-year medical students enrolled in the Cardiovascular, Renal, and Respiratory Medicine II (HBD409) course at our institution were invited to participate in this randomized, controlled crossover study on a voluntary, extracurricular basis. Recruitment was conducted via an electronic mailing list. The UCLA Human Subjects Protection Committee approved the study as exempt from full IRB review.

### Study design

Students were randomized to four different groups (A, B, C and D) consisting of 4–6 students per group. Each group

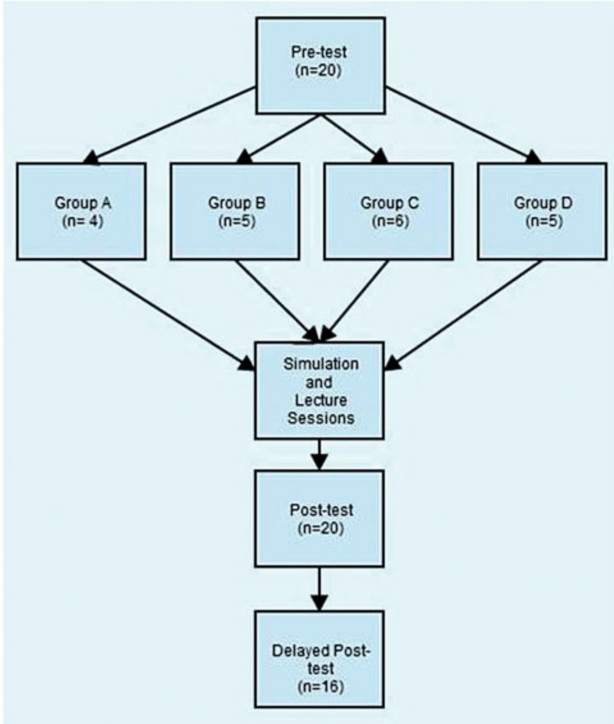


**Figure 1.** Flowchart describing the sequence of events from pre-test to delayed post-test.

received a combination of two simulator sessions and two lecture sessions on the following four topics: hyperkalemia (Hyper-K), ST-elevation myocardial infarction (STEMI), atrioventricular nodal reentry tachycardia (AVNRT) and Torsades de Pointes (Torsades) (Figures 1 and 2). Groups A and C received simulation sessions on hyperkalemia and AVNRT and lecture sessions on STEMI and Torsades (Figure 2). Groups B and D received the opposite combination of interventions (Figure 2). Four rooms were used simultaneously throughout the study and the four groups rotated through each of the four rooms. The instructors in each room remained the same to minimize inter-instructor variability. At the conclusion of four sessions, all students had learned about hyperkalemia, STEMI, AVNRT and Torsades via simulation or lecture (Figure 2). Four teaching points per topic were formulated and implemented into the simulator and lecture sessions to ensure consistency of information delivered.

### Simulator sessions

The METI (Medical Education Technologies, Sarasota, FL) high-fidelity patient simulator is a mannequin that can be programmed to emulate a breadth of clinical scenarios and physical examination findings. In addition, the mannequin can be connected to patient monitors that display hemodynamic and respiratory parameters and provide real-time response to interventions performed by users. All students had participated in simulator sessions before as part of their required curriculum and were thus familiar with the simulator system.

Each scenario lasted 20 min long and began with a case stem consisting of the patient's chief complaint, brief history of present illness and vital signs. Students were then allowed to

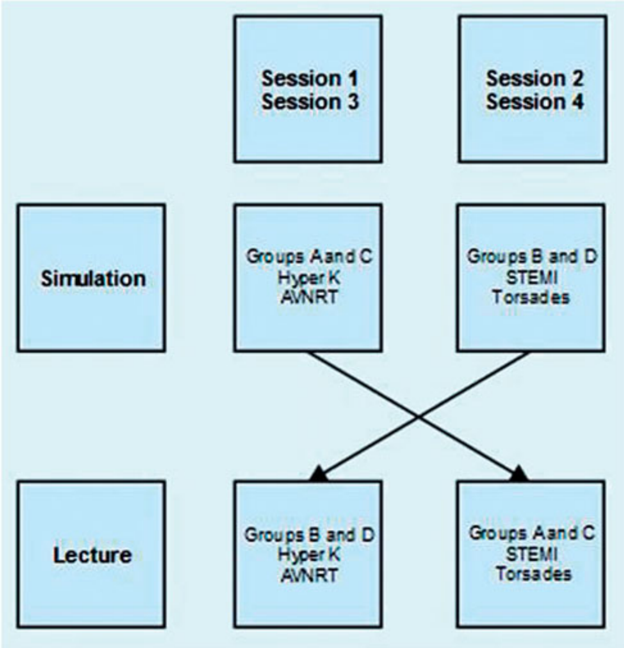


**Figure 2.** Diagram describing the randomized, controlled crossover method of our study.

perform physical examination maneuvers and ask further questions, which staff members could respond to via a speaker located below the head of the mannequin to simulate the patient's voice. After gathering more pertinent information, students were allowed to perform interventions, such as order diagnostic tests or administer drugs. Throughout the simulation, staff members assumed the role of the nurse and other ancillary staff, and a faculty investigator acted as a facilitator to help students navigate the clinical scenario.

Following the clinical scenario, a 10-min debriefing session was led by the faculty investigator in which students had the opportunity to deconstruct their thought process and ask questions. For each topic, the pre-determined teaching points were emphasized during the de-briefing session.

### Lecture sessions

For each topic, 30-min lectures were held in which four pre-determined teaching points were emphasized (identical to those taught in the simulator sessions). These sessions were held in a traditional lecture-based format in which pertinent outlines and diagrams were drawn on a whiteboard. Students were encouraged to interact with instructors by answering and asking questions throughout the session.

### Intervention assessment

Prior to conducting the lecture and simulation sessions, the authors created nine multiple choice-questions for each topic covered. Each question tested a specific pre-determined teaching point for that topic. Sample questions were as follows: "Which of the following symptoms or signs is unlikely in a patient with an inferior wall myocardial infarction?", or "A patient presents to the ER with suspected hyperkalemia secondary to renal failure. What is the next best step in management?", or "Which of the following is not an EKG sign consistent with hyperkalemia?"

The nine multiple-choice questions for each topic were randomly divided into three groups, resulting in three tests consisting of 12 questions each. These three tests were randomly assigned as the "pre-test", "post-test" and "delayed post-test". The pre-test was completed immediately before and the post-test was completed immediately after the teaching sessions. Both the pre-test and post-test were completed on paper in a proctored and closed-book setting. The delayed post-test was conducted 5 weeks post-intervention via an online test. Students were incentivized to complete the delayed post-test with a gift card in the amount of $5 following submission of their answers. All tests were de-identified using an 8-digit code unique to each participant. Tests were scored by using an answer key that was written prior to administration of the tests. The scorers of the test were blinded to the intervention.

### Data analysis

All data was collected in a blinded manner and segregation of participant identity and individual scores was maintained. Multiple choice questions from the pre-test, post-test and delayed post-test were graded and total individual scores were determined. The overall average percent correct among all participants within the simulation and lecture groups was calculated. Average percent correct in a given subject was also calculated. The average change in percentage correct from pre-test to post-test and post-test to delayed post-test was calculated for the simulation and lecture groups. These numbers were also stratified to calculate the average change in percentage correct in a given subject taught by simulation or lecture.

A comparison of the average percentage correct between the pre-test, post-test and delayed post-test was performed across all the four subjects and by each subject to assess the individual efficacy of simulation- and lecture-based education. A cross-method comparison of the average change in percentage correct between pre-test and post-test and post-test and delayed post-test was performed, comparing simulation- to lecture-based education across all the four subjects and individual subjects. The two-tailed Student's *t*-test was used to assess for statistical difference between pre-test, post-test and delayed post-test and across interventions. The Shapiro–Wilks test was used to evaluate the test scores for normality (Gaussian distribution). A $p$ value less than 0.05 was considered significant. Statistical analysis was performed using IBM SPSS, version 19 (Armonk, NY).

## Results

A total of 20 second-year medical students were voluntarily enrolled in the study. Ten students were randomized to groups A and C, which received simulation sessions on hyperkalemia and AVNRT, and lecture sessions on STEMI and Torsades de Pointes. Ten students were randomized to groups B and D, which received simulation sessions on STEMI and Torsades de Pointes, and lecture sessions on hyperkalemia and AVNRT

**Table 1.** Average percentage correct in simulation-based learning across all four subjects and by individual subjects.

| | Pre-test (%) | Post-test (%) | Delayed post-test (%) |
|---|---|---|---|
| Individual subjects | ($n=10$) | ($n=10$) | ($n=8$) |
| Hyperkalemia | 30.00 ± 24.58 | 50.00 ± 32.39 | 91.67 ± 15.43 |
| *p* Value | 0.137 | 0.004 | |
| STEMI | 43.33 ± 31.62 | 83.33 ± 17.55 | 79.17 ± 24.80 |
| *p* Value | 0.002 | 0.682 | |
| AVNRT | 40.00 ± 34.42 | 50.00 ± 23.57 | 87.5 ± 17.25 |
| *p* Value | 0.458 | 0.002 | |
| Torsades | 46.67 ± 32.20 | 36.67 ± 18.92 | 58.33 ± 23.57 |
| *p* Value | 0.408 | 0.045 | |
| All subjects combined | ($n=20$) | ($n=20$) | ($n=16$) |
| | 40.00 ± 21.89 | 55.00 ± 18.02 | 79.17 ± 18.76 |
| *p* Value | 0.023 | <0.001 | |

*p* Values represent improvement from pre-test to post-test and post-test to delayed post-test.

**Table 2.** Average percentage correct in lecture-based learning across all four subjects and by individual subjects.

| | Pre-test (%) | Post-test (%) | Delayed post-test (%) |
|---|---|---|---|
| Individual subjects | ($n=10$) | ($n=10$) | ($n=8$) |
| Hyperkalemia | 43.33 ± 31.62 | 76.67 ± 22.49 | 87.5 ± 22.50 |
| *p* Value | 0.014 | 0.346 | |
| STEMI | 33.33 ± 27.20 | 90.00 ± 16.09 | 54.17 ± 17.23 |
| *p* Value | <0.001 | <0.001 | |
| AVNRT | 53.33 ± 35.82 | 46.67 ± 35.82 | 70.83 ± 27.80 |
| *p* Value | 0.682 | 0.137 | |
| Torsades | 46.67 ± 32.20 | 53.33 ± 17.20 | 58.33 ± 29.54 |
| *p* Value | 0.571 | 0.659 | |
| All subjects combined | ($n=20$) | ($n=20$) | ($n=16$) |
| | 41.17 ± 20.42 | 66.67 ± 19.49 | 67.71 ± 22.33 |
| *p* Value | 0.001 | 0.882 | |

*p* values represent improvement from pre-test to post-test and post-test to delayed post-test.



(Figure 2). Four students were lost to follow-up. These students were included in pre-test and post-test analysis, but were excluded from delayed post-test analysis. To confirm that our randomization groups were accurate, all students were given the same pre-test. The simulation group scored a mean of 40.00% ± 21.89% and the lecture group scored 41.17% ± 20.42% ($p=0.538$). Further stratification by individual subject also demonstrated similar pre-test scores between both the groups across all subjects ($p>0.05$).

Both the simulation and lecture groups demonstrated significant improvement from pre-test to post-test ($p=0.023$, $p=0.001$, Tables 1 and 2). Stratification by subject demonstrated significant increases only in the lecture hyperkalemia and STEMI groups ($p<0.05$, Tables 1 and 2). From post-test to delayed post-test, the simulation group demonstrated significant improvement, while the lecture group scores remained similar ($p<0.001$, $p=0.882$, Tables 1 and 2). Stratification by subject revealed significant increases in the simulation groups for hyperkalemia, AVNRT and Torsades ($p<0.05$, Table 1). Only the STEMI lecture group demonstrated improvement from post-test to delayed post-test ($p<0.05$, Table 2).

To compare the two interventions to each other, average individual student improvement was calculated between pre-test to post-test and post-test to delayed post-test. Both interventions demonstrated similar mean individual student improvement from pre-test to post-test ($p=0.340$, Table 3). Further analysis by subject demonstrated that all the four subjects demonstrated similar individual student improvement regardless of the intervention from pre-test to post-test ($p>0.05$, Table 3). The average individual student improvement from post-test to delayed post-test was significantly greater in students who learned via simulation compared to lecture ($p=0.036$, Table 3). When assessing the individual subjects, hyperkalemia and STEMI had greater mean individual student improvement scores ($p\leq 0.05$, Table 3) while AVNRT and Torsades had similar mean individual student improvement scores from post-test to delayed post-test ($p>0.05$, Table 3).

## Discussion

Multiple studies have demonstrated equivalent or superior performance on immediate post-tests when comparing simulation to lecture-based education among medical students (Kasturi et al. 2009; Gordon et al. 2006; Wong et al. 2007; Bassily-Marcus et al. 2010; McCoy et al. 2011; Li et al. 2012). Our study is consistent with these findings. Both the simulation and lecture groups demonstrated significant improvement from pre-test to post-test and there was no difference in individual student improvement when comparing the two interventions across these tests.

Although both learning modalities demonstrated equivalent gain in immediate knowledge, the acquisition of knowledge by the two modalities is different. Lecture-based learning is largely based on explicit memory, which is the direct recollection of previously attained information (Schacter et al. 1993). On the other hand, simulation allows for the development of implicit memory, which derives from subconscious thought processes (Schacter et al. 1993). Implicit memory is triggered by observing cues (patient has chest pain and ST elevations) and associating them with appropriate actions (activate the catheterization lab) rather than being directly presented with facts in verbal or written format. Additionally, simulation allows for a "priming" phenomenon. Priming is a well-described psychological principle that refers to increased sensitivity to certain stimuli following a prior exposure. The exposure is thought to further contribute to implicit memory development.

In our study, we postulate we may have witnessed the priming phenomenon in full effect. The simulation group demonstrated a statistically significant improvement in test scores between the immediate and the delayed post-test, while the lecture group did not. After being exposed to activating scenarios where the outcomes of the simulated patients depended on the students' knowledge of the pathophysiology of certain conditions, such as hyperkalemia, STEMI, AVNRT and Torsades, students may have later been more engaged when studying these topics in their course or during

**Table 3.** Average individual student improvement between pre-test to post-test and post-test to delayed post-test comparing simulation- and lecture-based learning.

| | Pre-test to post-test | | | Post-test to delayed post-test | | |
|---|---|---|---|---|---|---|
| | Simulation (%) | Lecture (%) | *p* Value | Simulation (%) | Lecture (%) | *p* Value |
| Individual subjects | ($n=10$) | ($n=10$) | | ($n=8$) | ($n=8$) | |
| Hyperkalemia | 20.00 ± 28.11 | 33.33 ± 44.44 | 0.433 | 50.00 ± 35.62 | 12.50 ± 35.35 | 0.053 |
| STEMI | 40.00 ± 26.29 | 56.66 ± 22.49 | 0.145 | − 8.33 ± 23.57 | − 37.50 ± 11.75 | 0.007 |
| AVNRT | 10.00 ± 38.64 | − 6.67 ± 46.61 | 0.396 | 37.50 ± 27.80 | 25.00 ± 38.82 | 0.471 |
| Torsades | −10.00 ± 38.64 | 6.67 ± 40.98 | 0.362 | 20.83 ± 39.59 | 8.33 ± 42.72 | 0.554 |
| All subjects combined | ($n=20$) | ($n=20$) | | ($n=16$) | ($n=16$) | |
| | 15 ± 18.63 | 22.5 ± 29.26 | 0.340 | 25.00 ± 30.43 | 2.08 ± 28.46 | 0.036 |

independent study. With so much material to cover in preclinical courses, students often struggle to decide where to spend their time and effort. It is possible that after seeing simulations based on realistic clinical scenarios students saw the value and clinical applicability of learning the simulated topics more in-depth. They may have also had improved focus secondary to the emotional engagement generated while teaching these topics during simulation. We may have also witnessed the superiority of implicit memory in long-term recall compared to explicit memory with the topic of STEMI. Critical knowledge related to understanding and managing this entity seemed to be mastered easily between pre-test and post-test but was retained better between post-test and delayed post-test in the simulation groups when analyzing individual student improvement. This significant finding in our study raises the discussion that simulation may be superior in teaching topics with a more clinical presentation, such as STEMI or pulmonary embolism than in subjects focused on diagnostic study interpretation such as AVNRT and Torsades.

In conclusion, we have attempted to explore the effect of simulation on long-term knowledge retention in undergraduate medical students. We implemented simulations for four cardiovascular and renal topics, and compared them to corresponding lecture-based sessions in a randomized, controlled, crossover format. Previous studies that have attempted to draw conclusions about this topic were limited by factors such as small number of simulations, participant drop-out and narrowly focused, non-clinically oriented topics, such as autonomic pharmacology that may have led to less emotional engagement than our topics, which were based upon realistic clinical scenarios (Kasturi et al. 2009; Reynolds et al. 2008; Bassily-Marcus et al. 2010).

This is the first study we are aware of that sought to demonstrate the greater efficacy of simulation-based learning in facilitating long-term knowledge retention compared to traditional lecture in preclinical medical students. The efficacy of simulation in developing long-term knowledge retention is likely a combination of developing implicit memory and "priming". We believe our work should lead to attempts at verification in varied pre-clinical settings with different topics or via different simulation modalities in larger sample sizes. Additionally, our study indicates that each modality is associated with equivalent immediate knowledge gain. Further studies are needed that assess immediate and long-term knowledge gain through a combination of simulation- and lecture-based learning, not just by isolating and comparing each learning modality.

Our study has limitations. The sample size of 20 was small and four were lost to long-term follow-up (20% dropout rate). Despite this, we were still able to demonstrate statistically significant differences between the two teaching modalities. Unlike the proctored immediate post-test, the delayed post-test was administered in an unproctored, online format introducing the possibility that students used additional resources to complete the test. With regards to recruitment, students were recruited on a volunteer basis, which may have resulted in a population that was more amenable to learning than the average student. Though all sessions were 30 min in length, simulations required preparation time in between sessions while lectures did not, possibly affording lecture leaders more time to discuss teaching points than simulation leaders. Additionally, the instructors of the teaching sessions were not blinded thus possibly leading to an ascertainment bias; however, the students were blinded as to the hypothesis of the study. Lastly, the post-test in our study was conducted after the participants had completed a mandatory final examination as part of their core curriculum. The topics on this final examination overlapped with the topics covered in our study likely contributing to the increase in scores seen on the delayed post-test. However, given the randomized crossover format, each participant served as his or her own control throughout the study, minimizing this effect. In fact, the superiority of simulation between the immediate post-test and delayed post-test raises the possibility that simulation may prime the learner to better assimilate information on that topic even after the simulated session. This could be an area of future study.

## Conclusion

When conducting multiple teaching sessions covering clinically relevant topics in cardiovascular and renal pathophysiology with preclinical medical students, simulation is similar in efficacy to lecture-based education using average scores on immediate post-tests as an endpoint. However, simulation may be better than traditional lectures in developing long-term knowledge retention. The superiority of simulation in this regard is likely secondary to its ability to sensitize students to subsequent exposures of the material and developing implicit memory, thereby allowing for better acquisition and retention of clinically relevant knowledge in the long-term.

## Glossary

**High-fidelity simulation:** Fidelity in simulation has traditionally been defined as "the degree to which the simulator replicates reality". Using this definition, simulators are labelled as either "low" or "high" fidelity depending on how closely they represent "real life".

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## Notes on contributors

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***Declaration of interest***: No public or private funding was received for this work. The primary investigator funded $80 to pay for 16 $5 gift cards for incentive to complete the delayed post-test.

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