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HOW WE TEACH | *Classroom and Laboratory Research Projects*

Remember to breathe: teaching respiratory physiology in a clinical context using simulation

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Bintley HL, Bell A, Ashworth R. Remember to breathe: teaching respiratory physiology in a clinical context using simulation. *Adv Physiol Educ* 43: 76–81, 2019; doi:10.1152/advan.00148.2018.— Evidence shows that biomedical knowledge is more effectively taught within the medical curriculum by teaching in context, to facilitate learning transfer. The purpose of the present study was to evaluate the effect of combining high-technology simulation and physiology teaching on medical student learning and experience. First-year medical students received respiratory physiology teaching in the form of lectures, problem-based learning, and practical sessions. These students were then given the opportunity to apply their knowledge and problem solve using respiratory-related clinical case scenarios in simulated patients. Student understanding was assessed using a short quiz performed immediately before and after the session. Results revealed that the session significantly improved the mean score on tests (6.97 ± 0.29 vs. 8.22 ± 0.19 , $P < 0.001$). Student evaluation was collected in focus groups, and recurring concepts were extracted from the data. Students reported that the sessions helped to bridge the gap between theory and practice, which aided their learning. In addition, this teaching methodology (simulation) was reportedly patient centered and added to the realism of the simulated scenario, with students stating that this teaching improved their confidence with managing real patients and clinical uncertainty. Simulation has been used extensively to teach clinical skills; however, research regarding its potential for teaching biomedical science within a clinical context is limited. Our study shows that combining high-technology simulation and physiology teaching contributed to an immediate improvement in medical student knowledge and enhanced their ability to make connections between theoretical knowledge and the world of practice.

learning transfer; respiratory teaching; simulation

INTRODUCTION

Biomedical science teaching in areas such as physiology, biochemistry, and anatomy forms an integral part of the medical curriculum. Scientific knowledge provides an important foundation for complex problem solving, diagnosis, and patient care within a clinical context (24, 25, 30). Several educational approaches can be used to facilitate the (cognitive) integration of basic and clinical science and enhance the transition from theoretical understanding to application in a work-based environment. The challenge is to introduce and optimise teaching strategies that enhance this learning transition throughout the medical program and beyond.

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Redesign of medical curricula has drawn heavily from the idea of “learning transfer,” in which the application of knowledge/skills learned in one area can be applied in another context (11, 22). An example of this is the use of integrative, problem-based learning, which has been shown to foster the process of transfer in medical education (21) and is now a well-established teaching method in many medical schools (4). Equally important to medical training is the idea of “recontextualization,” which recognizes that knowledge exists within the context in which it was generated, and thus changes in relation to practice within different settings (7). The idea of recontextualization is supported by studies demonstrating that cognitive integration of scientific knowledge within a clinical setting is enhanced by using multiple contexts and mixed practice during training (15–17).

Respiratory physiology is classically an area in which medical students struggle to understand core biomedical concepts (28). Within our institute, medical students are taught respiratory physiology via lectures, problem-based learning, and practical sessions in the early years in preparation for practice in the later years. This model of teaching promotes the acquisition of biomedical concepts; however, the opportunity for the students to apply their knowledge in different contexts is limited. In recent years, simulation has become widely used in medical education to advance the acquisition of clinical skills, improve team working, and encourage deliberate practice in the clinical environment (6, 14, 18). Typically used to teach clinical skills, simulation-based teaching can also be used effectively to reinforce core theoretical concepts in areas of health science, such as physiology (12). The potential for the use of simulation to enhance learning within the preclinical environment has yet to be realized fully (13).

This study investigated whether combining high-technology simulation and basic science teaching put learning into context within the early years of the medical curriculum. First-year graduate-entry students undertook examinations of simulated patients with one of two respiratory conditions [ventilation/perfusion (\dot{V}/\dot{Q}) mismatching, or restrictive vs. obstructive conditions]. Student learning was assessed immediately after the sessions using a short quantitative test, followed by focus groups to record the student perspective in terms of understanding, engagement, and putting learning into context.

METHODS

This study was conducted with the approval of the Research Ethics Committee, Queen Mary University of London, and students were asked to participate on an opt-out basis. Informed, written consent was

obtained before the study commencing, and all data were anonymized before analysis.

A total of 40 students were included from the first year of the Bachelor of Medicine, Bachelor of Surgery (MBBS) graduate entry course at Barts and the Royal London School of Medicine and Dentistry, Queen Mary University of London. The groups were all from the same year group and at the same point in the academic year in the same medical school. Students had been taught key concepts in respiratory physiology (including \dot{V}/\dot{Q} matching and air flow) within a lecture setting in the weeks before the simulation sessions. Lecture objectives included an introduction to the concept of the ventilation perfusion ratio (\dot{V}/\dot{Q}) [questions 3 and 4 (Q3 and Q4) in the knowledge test, APPENDIX A], a description of how the \dot{V}/\dot{Q} ratio changes under various pathological conditions, the differentiation between obstructive and restrictive lung disease, and the role of spirometry in the diagnosis of lung disease (Q5–Q7 in the knowledge test, APPENDIX A).

SimMan essential (Laerdal) is a high-technology robotic simulator that can simulate a range of clinical signs and is used within our department to teach clinical skills. For the class, two manikins were used as the simulated patients. Two respiratory-based medical cases that focused on \dot{V}/\dot{Q} mismatch (pulmonary embolism) and obstructive and restrictive respiratory conditions [chronic obstructive pulmonary disease (COPD)] ran concurrently in each session. Each scenario started with a simplified summary of the patient's history, including name, age, the presenting complaint and history of presenting complaint, past medical/surgical history, medication history, social and occupational history, and family history. The pulmonary embolism case was based on a hospitalized 55-yr-old female patient who had recently undergone an open surgical approach for a cholecystectomy. Due to concerns over potential bleeding from the wound, several doses of chemical thromboprophylaxis had been missed postoperatively. The patient complained of new-onset, pleuritic-sounding chest pain and breathlessness and has a background of hypertension and being overweight. When assessed oxygen saturations were 86% on room air, with a respiratory rate of 31 breaths/min. Blood pressure was 162/95 mmHg, pulse rate was 128 beats/min, and ECG showed sinus tachycardia. An arterial blood-gas sample showed the patient to be hypoxic, in type 1 respiratory failure, and hypocarbic. The COPD case was based on a 60-yr-old male patient presented in winter with worsening shortness of breath and productive cough. The patient was known to have COPD diagnosed 5 yr previously using National Institute for Health and Clinical Excellence guidance diagnostic criteria and had stopped smoking with help from the National Health Service Stop Smoking Service at the point of diagnosis, but had smoked 40 cigarettes a day for 35 yr. The patient has some symptoms and is currently on Salmeterol 50 mg (1 puff twice daily), but has, up to this point, never experienced an exacerbation of his COPD. He is up to date with vaccines, attends all follow-up appointments, and says he is compliant with treatment. These findings were used to guide student management of the case and focus discussion points.

Students were divided into two groups (20 students) and given a 1-h SimMan teaching session. Within each group, the class was split into half, and 30 min were allocated to each scenario so that a total of 10 students worked to complete each case (see APPENDIX B, study plan). Details of the cases were not disseminated to the students before the teaching session. The teaching was supported by the authors (a combination of clinical and nonclinical teaching faculty), but self-directed, collaborative learning was encouraged, and students were expected to lead the management of the simulated patient. Understanding of \dot{V}/\dot{Q} matching and obstructive and restrictive respiratory conditions was assessed immediately before and after the simulation sessions. The students were asked to complete a matched pre-post MCQ/SAQ knowledge test based on subject material delivered in respiratory physiology lectures and revisited during the simulation sessions (APPENDIX A). Marks were collated and expressed as mean percentage and standard deviation (SD) of the marks. Students with

incomplete data sets were excluded from analysis. Any difference in mean performance between the two groups for each module was determined using either a one-way ANOVA with Tukey-Kramer multiple-comparisons test or paired *t*-test using InStat (GraphPad Software), with results considered significant if $P < 0.05$.

The study used focus groups as a tool to gather a variety of student viewpoints of their experience in this learning environment (3, 26). Four focus group interviews were conducted one after another immediately after the simulation, and all students who completed the knowledge test completed the focus group. Two focus groups were conducted with two sets of 10 students per group. The sample population was assigned at random to a focus group dependent on centralized timetabling. The focus group lasted 45 min and consisted of students being asked semistructured questions. In line with the research aims, these questions included enquiry about the experiences, knowledge gains, and challenges faced by the students during the teaching intervention (APPENDIX C). The focus group interviewer was not involved in the day-to-day teaching of the participants and was not associated with the research in any other aspect. There were no financial or academic incentives given to students as part of the study. The interviewer asked students to discuss the questions in groups of five and wrote field notes on the answers they gave, both in these small groups and in a whole group discussion. At the end of the focus groups, the interviewer checked that the notes he/she had made reflected an accurate representation of the students' views.

One of the researchers performed a manual theme extraction of the data individually, identifying passages that illustrated recurring concepts (3, 26). This was also done separately by an experienced, independent academic not associated with the project. Any discrepancies in theme generation were discussed, and only themes agreed to by both academics were used in the results. Major and minor themes were based on the number of times they recurred in the focus group conversations, and the cutoff for qualifying as a major theme was being mentioned four times or more. Fifteen themes were identified, of which nine were noted by both of the academics undertaking the data analysis. The data analysis was based on field notes, not verbatim transcriptions, which may have affected interpretation of the results and the themes generated. All identifying information was removed before analysis to maintain the anonymity of the participants.

RESULTS

Knowledge test scores. Results for pre- and postsession knowledge tests were averaged for each question, and mean overall scores were calculated (Fig. 1). On comparison of mean individual question scores pre- and postsession, participants demonstrated an increase in average score in all but one question. The average for Q4 was 0.92 (SD 0.28) both pre- and postsession. The largest increase in the mean scores between pre- and postsession occurred in Q2 and Q3, where a one-way ANOVA with post hoc tests indicated a significant increase in mean scores [for Q2 an increase from 1.33 (SD 0.86) to 1.81 (SD 0.40), $P = 6.172$, and for Q3 an increase from 0.69 (SD 0.71) to 1.14 (SD 0.64), $P = 5.687$].

Collectively, the student group obtained a mean score of 6.97 (SD 1.73) out of 10 in the presession knowledge test, compared with a mean score of 8.22 (SD 1.12) when tested again immediately following the teaching session (Fig. 2). Analysis using paired *t*-test revealed this improvement in mean scores between the pre- and posttests to be statistically significant ($P = 0.0002$). Thus our results indicate that the teaching session contributed to an immediate improvement in student knowledge.

Focus group results. Quotations from the focus group, based on theme, are illustrated in Table 1. In terms of confidence in

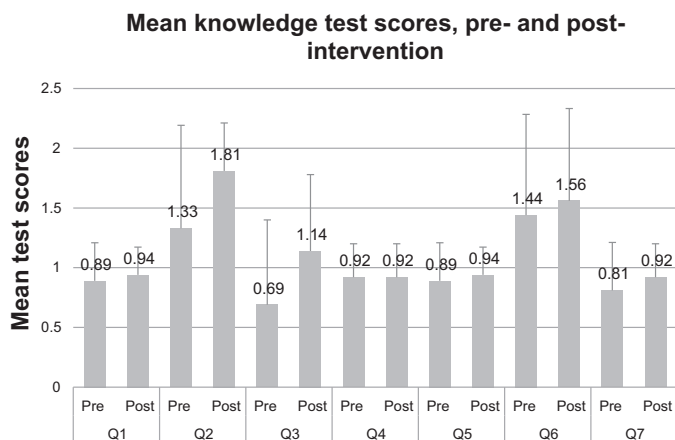


Fig. 1. Mean assessment scores for each question in the knowledge test, comparing pre- (Pre) and postsession (Post) results. Students were provided with the same short (10-mark) knowledge-based Pre and Post multiple-choice question/short-answer question knowledge test, which they completed before (Pre) and after (Post) the session. Results are means (SD) in percent for each question for both the pre- and posttests; $n = 36$ students. Q1–Q7, questions 1–7. Although marks varied between questions, a one-way ANOVA with Tukey-Kramer multiple-comparisons test showed that it was only in Q2 and Q3 that the marks between Pre and Post differed significantly ($P < 0.01$ and $P = 6.172$ for Q2, and $P = 5.687$ for Q3).

managing real patients and clinical uncertainty, students discussed improved practical skills, being able to find signs that they had previously not been able to elicit, being able to systematically assess a patient and encountering real-to-life scenarios. With respect to patient-centered and contextualized learning, students discussed relating basic science knowledge to clinical pathology, applying theory to practice, and learning in a different, “fun” way, which aided their learning. Students also commented that the scenarios, using SimMan, were realistic, that this added to their learning experience, and that the session was interactive. Suggestions for improvement included a need for more prereading and preparation before the session and smaller group sizes so that everyone gets a chance to practice using the manikin.

DISCUSSION

Influenced by educational theory as well as observation and reflection in practice, this study evaluated the use of high technology simulation to recontextualize core concepts in physiology and potentially facilitate learning transfer during the early years of the MBBS program. The outcomes of this study demonstrated the effectiveness and feasibility of this teaching design. Evidence of the immediate improvements in quantitative knowledge gain was supported by qualitative data, indicative of an enhancement of the student experience with the opportunity to apply scientific knowledge within a more realistic, clinical environment.

Our rationale for using the pre- and postsession knowledge recall test was to establish the immediate effect of the novel simulation-based teaching session on student understanding of respiratory concepts taught previously in lectures. The quantitative data from matched pre-post knowledge tests showed a significant improvement in subject knowledge immediately following the session and supports our expectation that the use of simulation to teach physiology concepts improved student understanding. However, there are several limitations to this

pilot study that need to be explored further. First, the present data indicate the acquisition of short-term gains, but do not provide information on longer term knowledge retention. Second, the goal is to determine whether this approach is useful to develop the integration of basic and clinical science and as a learning tool for the students to bridge the gap between knowledge and practice. Our study did not directly address the effectiveness of the simulation on improving the student’s ability to apply their knowledge in practice. Learning transfer has been tested in various ways, primarily using case studies to assess student’s understanding and diagnostic reasoning using quantitative measures (31). These types of techniques should be employed in future studies to explore learning transfer in the context of the present study.

Improvement in student learning was supported by feedback received from the focus groups as part of qualitative research in this study. One major theme identified that the teaching intervention recontextualized student learning and helped to bridge the gap between theory and practice, supporting the idea that simulation helped put biomedical knowledge into context. Evidence shows that good understanding of basic science is key to the development of clinical expertise and is most effectively taught in a manner in which the relationship between causal mechanism and disease is made explicit (29). Basic science knowledge serves as a framework for the organization of clinical knowledge (learning transfer/recontextualization), and this can be optimized by emphasis of the core biological concepts taught alongside sessions that expose learners to multiple contexts in which these concepts apply (17). In summary, our results showed that the session had an immediate positive impact on learning and support the use of this approach as a supplementary strategy for teaching within the existing curriculum.

Another of the major themes identified in student feedback reported that this teaching methodology (simulation) was patient centered and added to the realism of the simulated scenario, with students stating that the teaching improved their confidence with managing real patients and clinical uncer-

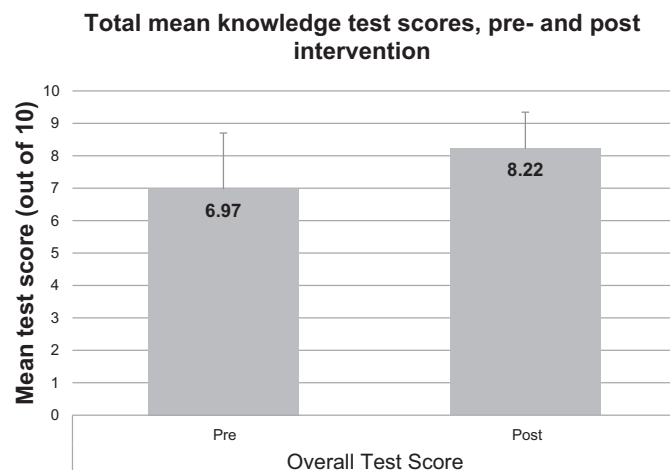


Fig. 2. Overall mean assessment scores revealed improved scores following the teaching session. Students were provided with the same short (10-mark) knowledge-based pre-session (Pre) and postsession (Post) multiple-choice question/short-answer question knowledge test, which they completed before (Pre) and after (Post) the SimMan session. Values are means (SD) in percent of marks for the pre- and posttests; $n = 36$ students. A paired t -test showed the mean scores for the Pre and Post differed significant ($P = 0.0002$).

Table 1. *Outcomes from the focus groups*

Themes	Quotes Assigned to Each Theme
	<i>Major</i>
This teaching improved my confidence with managing real patients/clinical uncertainty.	“Useful to hear clinical signs.” (Line 37) “It will help me to think systematically.” (Line 33)
The combination of physiology teaching and simulation technology bridged the gap between theory and practice.	“Scenarios you might actually encounter made it feel interesting.” (Line 51) “It clarified knowledge and how it relates to pathology.” (Line 28) “I learned things . . . things like equations make more sense when you see a clinical scenario.” (Line 29/30)
This teaching methodology was patient centered and contextualized learning as such.	“Applying my knowledge has been really useful.” (Line 34) “Learning can be quite dry and quick, and this was fun, made sense of our knowledge and helped to relate the pathology to the patient.” (Line 31/32) “It improved our understanding; it applied our knowledge and put it into context.” (Line 83) “Explanations linked to clinical scenarios really helped.” (Line 86)
This teaching methodology added to the realism of the simulated scenario.	“It was good . . . realistic.” (Line 75) “They were scenarios you might actually encounter, made it feel interesting.” (Line 51) “Very realistic.” (Line 20)
Not everyone got hands-on experience with the manikins.	“Have smaller groups . . . not everyone got to ‘lay hands’ on the SimMan.” (Line 13) “Didn’t all get to use it.” (Line 19) “Small student groups but could be even smaller.” (Line 49)
More preparation for the session would have been useful for learning during the session.	“More insight about what it will be on before session.” (Line 59) “More prereading.” (Line 62) “Summary sheet of needed info would be good.” (Line 70)
	<i>Minor</i>
The teaching methodology made the session more interactive.	“Really good, interactive way of learning.” (Line 47)
The teaching methodology allowed students to find clinical signs that they had not found before.	“Really useful to hear what the breath-sounds are like . . . often just examine each other.” (Line 21/22)
The teaching methodology needs to be an established part of the MBBS curriculum.	“We would like these regularly, like the surface anatomy sessions.” (Line 35/36) “Please can we use SimMan more in the session?” (Line 68)

Line numbers are in direct reference to the transcription of the field notes. MBBS, Bachelor of Medicine, Bachelor of Surgery.

tainty. It is important that medical students can adapt to change and manage uncertainty in the clinical environment to provide patient-focused, holistic care and adapt to an ever-changing health system. However, students often do not feel confident to manage uncertainty, and this causes them significant mental strain (20). Managing uncertainty can also be a relatively abstract concept for a student group that could be argued to be, overall, positivist thinkers (9). The authors used elements of Bruner’s (1) and Vygotsky’s work (27) on educational psychology to implement a staged, scaffolding approach to support students’ learning. With a sociocultural lens, the authors accepted that, particularly in multidisciplinary scenarios, such as simulated medical emergencies, knowledge is co-constructed with other learners and influenced heavily by environment. We created a realistic hospital ward environment and designed scenarios that required collaborative working and learning with other students. This was supported with “concrete” (1) facts in the form of lectures before the session and scaffolded involvement of educators during the sessions, which are recognized techniques to help students gain a more advanced understanding of both anatomy and physiology (5).

Importantly, high-technology simulation applies to the first two levels of Miller’s framework for clinical assessment (19), meaning that educators can program specific learner content, give students a standardized experience, and provide measurable outcomes. Work has identified four key areas that underpin simulation-based learning, and, although these are more directed toward the acquisition of procedural skills within clinical practice, they could as easily be applied to the use of simulation in the early years of learning (14). Despite their extensive use in medical training and evidence to show that high-fidelity patient simulators

are an effective teaching tool for key concepts of human physiology, they remain underutilized (13). Obstacles to the introduction of patient simulators into physiology teaching include cost and concerns over fidelity compared with more traditional teaching methods. There is evidence to show that there are very little gains between high-fidelity compared with low-fidelity simulation (23). However, utilizing high-technology simulation equipment in more diverse ways, such as teaching of the underlying sciences, makes the investment in simulation technology even more justifiable. One of the strengths of human simulation lies in its ability to demonstrate pathophysiological concepts under different conditions (2, 12). Within the context of our study, cost was not a limiting factor, and the introduction of high-fidelity patient simulators proved effective in enabling students to recontextualize their understanding of key physiological concepts in a more clinically focused setting. We are now exploring the possibility of how to deliver simulation teaching to larger cohorts of undergraduate students.

The qualitative analysis also captured in our study provides potential areas for improving the teaching methodology. Suggestions of additional preparation materials were discussed by participants throughout the focus groups. Also, students asked for more real-time involvement from educators during the session and summary sheets at the end. Despite attempts, as discussed above, to scaffold and frame this teaching to support students better, it would appear that this could have been done more explicitly. This could have potentially occurred because the technology, as well as the concepts and the type of teaching intervention, were all new to the students, causing a degree of cognitive overload (32). Future work in this area may look at introducing techniques shown to be effective around the management of uncertainty, including self-

directed group work before the session, web-based simulation preceding the simulation session, and students creating their own summary sheets after the sessions (8, 10).

In conclusion, this study demonstrates the feasibility of using high-fidelity simulation to teach physiology to medical students. These results support the use of simulation to improve student learning, facilitate engagement, and potentially promote learning transfer within the early years training. This preliminary study demonstrates the effectiveness of simulation for delivering key physiological concepts within different clinical contexts. Furthermore, it supports the potential of simulation teaching as a strategy to facilitate learning transition during the early years of medical school. This was a small study and the outcomes illustrated here need to be replicated with a larger representative sample before they can be generalized to other student populations in the UK. However, the study showed quantitative improvements in learning, as well as qualitative evidence that the intervention recontextualizes students' learning and helps them to manage clinical uncertainty. We aim to learn from the feedback that we received in the construction of this intervention and repeat this study with a larger cohort of students at our institution.

APPENDIX A: MULTIPLE-CHOICE QUESTION/SHORT-ANSWER QUESTION KNOWLEDGE TEST

- The portion of the total ventilation that reaches the alveoli and participates in gas exchange is termed? (1 mark)
 - Alveolar ventilation
 - Minute ventilation
 - Physiological dead space
 - Residual volume
 - Vital capacity
- Define the term cardiac output. (2 marks)

The volume of blood pumped by the heart per minute [can be defined as the product of the heart rate (number of beats per minute) and the stroke volume].
- Define ventilation-perfusion (\dot{V}/\dot{Q}) ratio. (2 marks)

- Alveolar ventilation/cardiac output (1 mark for each term)
- The apex of upright lung has greater ventilation than perfusion; therefore, the ventilation/perfusion ratio would be? (1 mark)
 - Greater than one
 - Infinity
 - Less than one
 - One
 - Zero
 - Obstructive lung disease is a category of respiratory disease characterized by airway obstruction. Which of the following lung function measurements is a strong indicator of obstructive lung disease? (1 mark)
 - Decreased FVC
 - Decreased residual volume
 - Reduced FEV₁
 - Increased peak expiratory flow rate
 - Increased vital capacity
 - State how the FEV₁/FVC ratio is affected in restrictive lung disease. (2 marks)

FEV₁/FVC ratio is normal as all lung volumes are reduced (FEV₁ and FVC are reduced).
 - Spirometry, which reveals a mild degree of obstruction that is highly responsive (significant reversibility) to a bronchodilator, is a strong indicator of: (1 mark)
 - Asthma
 - Chronic bronchitis
 - Cystic fibrosis
 - Emphysema
 - Fibrosis

The correct answers are underlined.

APPENDIX B: STUDY PLAN

Figure B1 shows the study plan.

APPENDIX C: FOCUS GROUP QUESTIONS

- What did you like best about the session and why?
- What would you change about the session and why?

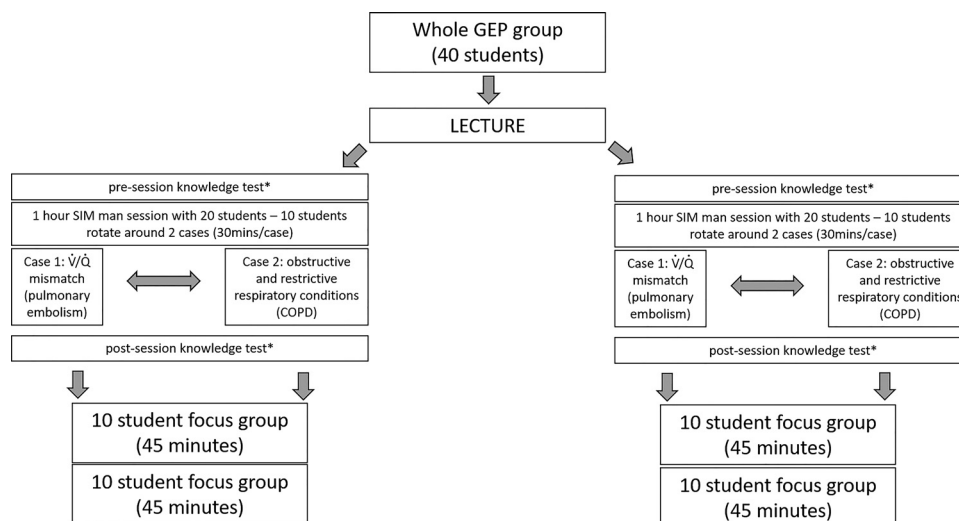


Fig. B1. Summary of the study plan. A total of 40 students from the first year of the Bachelor of Medicine, Bachelor of Surgery (MBBS) graduate entry course (GEP) were initially taught within a lecture setting in the weeks before the simulation sessions. Students were then divided into two groups (20 students) and given a 1-h SimMan teaching session. Within each group, the class was split into half, and 30 min were allocated to each scenario, so that a total of 10 students worked to complete each case. Knowledge was assessed immediately before and after the simulation sessions using a matched pre-session and post-session multiple-choice question/short-answer question knowledge test. Four focus group interviews (two for each session) were conducted immediately after the simulation. All students who completed the knowledge test completed the focus group. See METHODS for further details. COPD, chronic obstructive pulmonary disease; \dot{V}/\dot{Q} , ventilation/perfusion. *Note: Students with incomplete data sets were excluded from analysis (as described in METHODS).

3. What was it like using SimMan?
4. How has the session affected your understanding of \dot{V}/\dot{Q} mismatch and obstructive/restrictive conditions?
5. Suppose you had 1 min to talk to the dean about the topic of today's discussion. What would you say?

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

H.L.B., A.B., and R.A. performed experiments; H.L.B. and A.B. analyzed data; H.L.B., A.B., and R.A. interpreted results of experiments; H.L.B., A.B., and R.A. drafted manuscript; H.L.B., A.B., and R.A. edited and revised manuscript; H.L.B., A.B., and R.A. approved final version of manuscript; A.B. and R.A. prepared figures.

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