Mechanical Ventilation Training Curriculum for Pulmonary Critical Care Fellows during the COVID-19 Pandemic

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ABSTRACT

Background: Mechanical ventilation (MV) management is an essential skill for pulmonary and critical care medicine (PCCM) fellows to master during training. The unprecedented emergence of the coronavirus disease (COVID-19) pandemic highlighted the need for advanced operator competency in MV to improve patients' outcomes.

Objective: We aimed to create a standardized case-based curriculum using a blended approach of high-fidelity simulation, rapid-cycle deliberate practice, video didactics, and hands-on small group sessions for rapid accumulation of knowledge and hands-on skills for PCCM fellows before caring for critically ill patients during the COVID-19 pandemic.

Methods: The MV curriculum consisted of the following steps: *1*) baseline written knowledge test with 15 multiple-choice questions covering MV, the latest evidence-based practices, and pathophysiology of COVID-19; *2*) baseline confidence survey using a 5-point Likert scale; *3*) a one-on-one session using a high-fidelity simulation manikin, a lung simulator, and a mechanical ventilator to test baseline competencies;

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4) a structured debriefing tailored per fellow's 50-point competency assessment checklist from the simulation using rapid-cycle deliberate practice; *5*) video didactics; *6*) a hands-on session in small groups for basic knobology, waveforms, and modes of MV; *7*) a one-on-one simulation reassessment session; *8*) a written knowledge posttest; and *9*) a post-training confidence survey using a 5-point Likert scale.

Results: Eight PCCM fellows completed the training. The mean multiple-choice question score increased from 7.4 ± 2.9 to 10.4 ± 2.4 ($P < 0.05$), and the simulation scores increased from 17.1 ± 4.4 to 30.8 ± 3.7 ($P < 0.05$). Comparing the simulation reassessment to the baseline, fellows showed significant improvement ($P < 0.05$) in assessing indications for MV; implementing rapid sequence intubation for patients with COVID-19; initiating MV and ventilator bundle per best practices; recognizing and managing mucous plugging, ventilator dyssynchrony, and evidence-based treatments for acute respiratory distress syndrome; and developing a care plan for proning. The post-training survey revealed improved learner confidence in all competencies.

Conclusion: This pilot MV curriculum using a blended approach was feasible and allowed PCCM fellows to significantly improve their knowledge and hands-on skills, allowing for the appropriate use of MV during the pandemic. Self-reported improvement scores further reinforced this. The emergent need for novice learners may again be necessary for future pandemic settings where standard training models requiring extensive training time are limited.

Keywords:
rapid cycle deliberate practice; mechanical ventilation training; medical education

Mechanical ventilation (MV) management is an essential skill for pulmonary and critical care medicine (PCCM) fellows to learn during their training (1). Management of mechanically ventilated patients is complex, requiring specific skills and knowledge that trainees usually acquire throughout fellowship training. A survey of 108 PCCM programs conducted in 2008 demonstrated that only 50% of fellows reported satisfaction with their education in MV. The survey concluded that education in MV during PCCM fellowships across the United States currently faces limited satisfaction from fellows because of the lack of a formally structured education program (2).

MV in PCCM fellowships often takes the form of didactic lectures by faculty and hands-on learning during rotations in intensive care units (ICUs). The unprecedented emergence of the coronavirus disease (COVID-19) pandemic has highlighted the need for operator competency in MV to improve patient outcomes. However, the hands-on bedside educational approach was compromised by the need to minimize the exposure of healthcare workers to patients with COVID-19. The advancement of simulation technology has allowed for the development of low-risk, hands-on clinical scenario testing in which trainees can learn scientific concepts and implement their knowledge in the clinical setting (3–8). Randomized controlled trials of high-fidelity simulation versus lecture-based education demonstrated that the former could serve as a viable learning mode in medical training and have greater retention than didactic lectures (4, 9–11).

The combination of high-fidelity simulation training and rapid-cycle deliberate practice (RCDP) has also been shown to enhance learners' ability to attain competency and mastery through repetitive guided practice in various medical professionals, including medical students, residents, and nursing students (12–14). RCDP is a simulation-based technique that involves learners repetitiously performing a simulation, with microdebriefing interjected by faculty during each session. Our objective is to create a standardized curriculum using a blended approach that includes RCDP, high-fidelity simulation, traditional didactic lectures, and hands-on small group sessions incorporating the latest evidence-based practices for COVID-19 and MV management for PCCM fellows.

METHODS

The curriculum was designed to assess first-year PCCM fellows' knowledge and competency regarding the following topics: indications for MV, implementation of rapid sequence intubation for patients with COVID-19, initiating MV and ventilator bundle per best practices, management of acute respiratory distress syndrome (ARDS), developing a plan of care for patients in prone position, together with troubleshooting of common ventilator scenarios such as mucous plugging, ventilator dyssynchrony, and auto–positive end-expiratory pressure (auto-PEEP).

The MV curriculum consisted of the following sequential steps.

Baseline Knowledge Test

The baseline knowledge test consisted of 15 multiple-choice questions (MCQs), including topics of ARDS, ventilator waveform identification, and the latest evidence-based practices for managing patients with COVID-19.

Initially, 50 MCQs were developed per competencies listed in Table 1 based on the American Board of Internal Medicine pulmonary and critical care certification examination questions. Discrimination and difficulty indices (DIs) were used to narrow from a pool of 50 questions to the final 15 listed in Appendix H in the data supplement. The degree of difficulty for each MCQ was calculated using a DI (ρ value), defined as the proportion of test-takers answering the item correctly (ρ = # correct answers/# all answers). Questions with DIs between 0.3 and 0.7 were retained, while all others were eliminated (15).

The DI for each item was calculated using the following standard formula:

DI = (#correct answers among 27% of subjects with the highest overall scores– #correct answers among 27% of subjects with the lowest overall scores)/# correct answers in the group with the highest scores)

Discrimination index of 0.3 or higher was acceptable (16, 17).

The internal consistency and reliability were calculated using item-total correlation and Cronbach α coefficient. In our study, a Cronbach α value of 0.8 or higher was accepted for internal consistency.

Eight PCCM fellows completed the final set of 15 MCQs before high-fidelity simulation testing. Questions were renumbered, and answer choices were randomized without modification using Qualtrics Research Suite.

Table 1. Baseline and post-training confidence survey results using a 5-point Likert scale with 5 as strongly agree

MV Competency Subjects	Baseline	Post-Training
Initiation of MV	3.6 ± 0.7	4.8 ± 0.5*
PPE donning/doffing	3.4 ± 0.5	4.1 ± 0.9*
Rapid sequence intubation during the COVID-19 viral pandemic	3.3 ± 0.5	4.1 ± 0.4*
COVID-19 clinical trials and medical management	3.9 ± 0.4	4.5 ± 0.5*
Auto-PEEP management	3.5 ± 0.5	4.8 ± 0.5*
Mucous plug management	4.4 ± 0.5	4.5 ± 0.5
Ventilator dyssynchrony	3.5 ± 0.5	4.1 ± 0.4*
ARDS management	3.4 ± 0.5	4.4 ± 0.5*
Refractory ARDS	3.4 ± 0.5	4.3 ± 0.5*
Prone ventilation during COVID-19 viral infection	3.3 ± 0.5	4.5 ± 0.8*
Administration/monitoring of paralytics in mechanically ventilated patients	2.8 ± 0.6	4.1 ± 0.6*
Safe and effective prone cardiopulmonary resuscitation in ventilated patients with COVID-19	3.3 ± 0.5	4.8 ± 0.5*
Liberation from MV	3.9 ± 0.4	4.6 ± 0.5*

Definition of abbreviations: ARDS = acute respiratory distress syndrome; COVID-19 = coronavirus disease; MV = mechanical ventilation; PEEP = positive end-expiratory pressure; PPE = personal protective equipment.
Data are presented as mean ± standard deviation.
*Statistical significance with $P < 0.05$.

Baseline Confidence Survey

A baseline confidence survey using a 5-point Likert scale (Appendix E) was completed after baseline MCQs.

High-Fidelity Simulation Baseline Test

A one-on-one 90-minute session was conducted using a high-fidelity simulation manikin (SimMan 3G; Laerdal), a lung simulator (ASL 5000 Lung Simulator; IngMar MEdical), and a mechanical ventilator to test baseline competencies within clinical scenarios. The lung simulator allowed for compliance values representing each clinical scenario. Simulated patient vital signs, diagnostic imaging, and laboratory values were visible on a monitor, allowing participants to see dynamic changes as they occurred during scenarios. Trainees were tested using seven sequential scenarios. Each scenario focused on specific competencies. During the session, trainees completed the scenarios, with an RCDP intervention after each scenario, and were assessed using a 50-point checklist. An outline of each scenario's basic premise and competencies tested are found in Appendix A. All equipment required for high-fidelity testing is listed in Appendix B, and a visual representation is shown in Appendix C.

Baseline Test Debriefing

A 10-minute structured debriefing session tailored to each fellow's knowledge gap as determined by a 50-point competency assessment checklist (Appendix D) was completed after the high-fidelity one-on-one simulation.

Video Didactics

Trainees viewed 160 minutes of short didactic videos with remote tracking for completion. The didactic videos included topics of MV competency and COVID-19 best practices, as per Table 1. Didactic video viewing and monitoring were completed using Edpuzzle (https://edpuzzle.com/). It requires that trainees watch the entire video and answer questions with immediate feedback before being allowed to continue (18).

Small Group Sessions

A 60-minute hands-on session in groups of one to three trainees was held using Puritan Bennett-840 (NeoMode 2.0; Medtronic) and Maquet SERVO-U ventilators (V.2.1), covering basic knobology, waveforms, and various modes of MV on each device.

High-Fidelity Simulation Reassessment

A one-on-one simulation reassessment using the same simulation setup and a mechanical ventilator to test the retention of baseline competencies was completed 2 weeks after baseline training.

Post-training Knowledge Test

A written knowledge test occurred 2 weeks after the initial baseline testing. The posttest used our original 15 MCQs, with randomization of questions and answers.

Post-training Confidence Survey

A post-training confidence survey using a 5-point Likert scale (Appendix E) was completed.

Statistical Analysis

Results are reported using mean ± standard deviation. Paired *t* test was used to compare mean trainee MCQ and competency assessment performance between pre-training (pretest) and after completion of our pilot study (posttest). For statistical analysis, SPSS was used (version 20; IBM Corp.). The significance level was defined as $P < 0.05$.

RESULTS

A total of eight PCCM fellows completed the training. The mean MCQ score increased from 7.4 ± 2.9 to 10.4 ± 2.4 (maximum of 15), which equated to an improvement of 20% ($P < 0.05$), and the simulation scores improved from 17.1 ± 4.4 to 30.8 ± 3.7 (maximum of 50 points), an improvement of 27.4% ($P < 0.05$) (Figure 1). Comparing the simulation reassessment with the baseline session, fellows showed statistically significant improvement in simulation-based skills ($P < 0.05$). Specifically, significant improvement was observed in the ability to assess indications for MV, implement rapid sequence intubation for patients with COVID-19, initiate MV and ventilator bundle per best practices, recognize and direct the management of mucous plugging, determine and solve ventilator dyssynchrony, deploy evidence-based practices for ARDS, and develop a care plan for patients in prone position. Improvement in recognition and correction of auto-PEEP and adherence to best practices in liberation from MV did not reach statistical significance. Figure 2 outlines individual trainees' pre- and

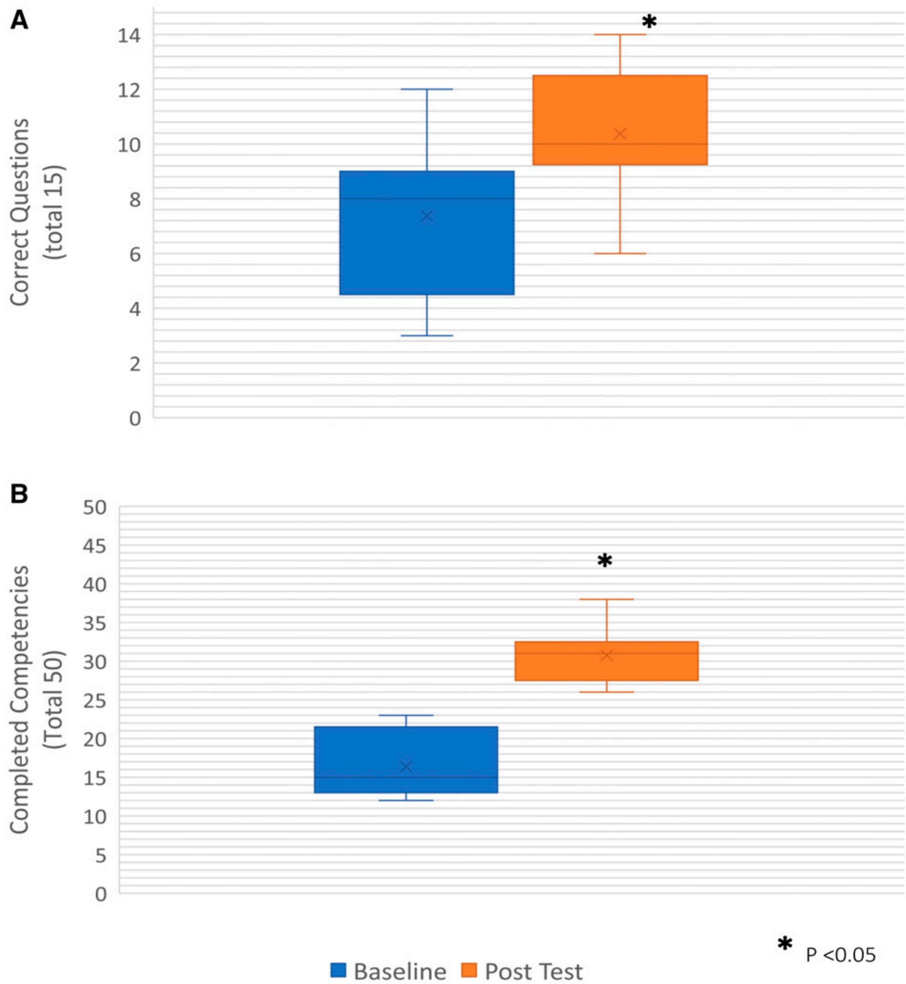

Figure 1. Box and whisker plots depicting improvement of the median scores for (*A*) the multiple-choice question–based knowledge test, and (*B*) the simulation-based competency skill assessment after 2 weeks of training ($P < 0.05$).

post-training performance on MCQ and simulation scores.

Baseline and post-training survey responses were completed by all trainees ($N = 8$, 100%). Table 1 demonstrates the baseline and post-training confidence survey results, which used a 5-point Likert scale, with 5 as strongly agree. Table 1 summarizes self-reported improvement in competencies related to managing MV during COVID-19. Improved learner confidence was seen in the 13 competencies assessed. Statistically significant improvement ($P < 0.05$) was found in all competencies except recognition and management of mucous plugging.

DISCUSSION

We studied the efficacy of a blended training curriculum during the COVID-19 pandemic using RCDP in a high-fidelity simulation to improve the knowledge and skills of fellows. In addition, our curriculum showed significant improvement in learner confidence. The results of this curriculum are consistent with previous studies showing improvement in competency after simulation-based critical care medical

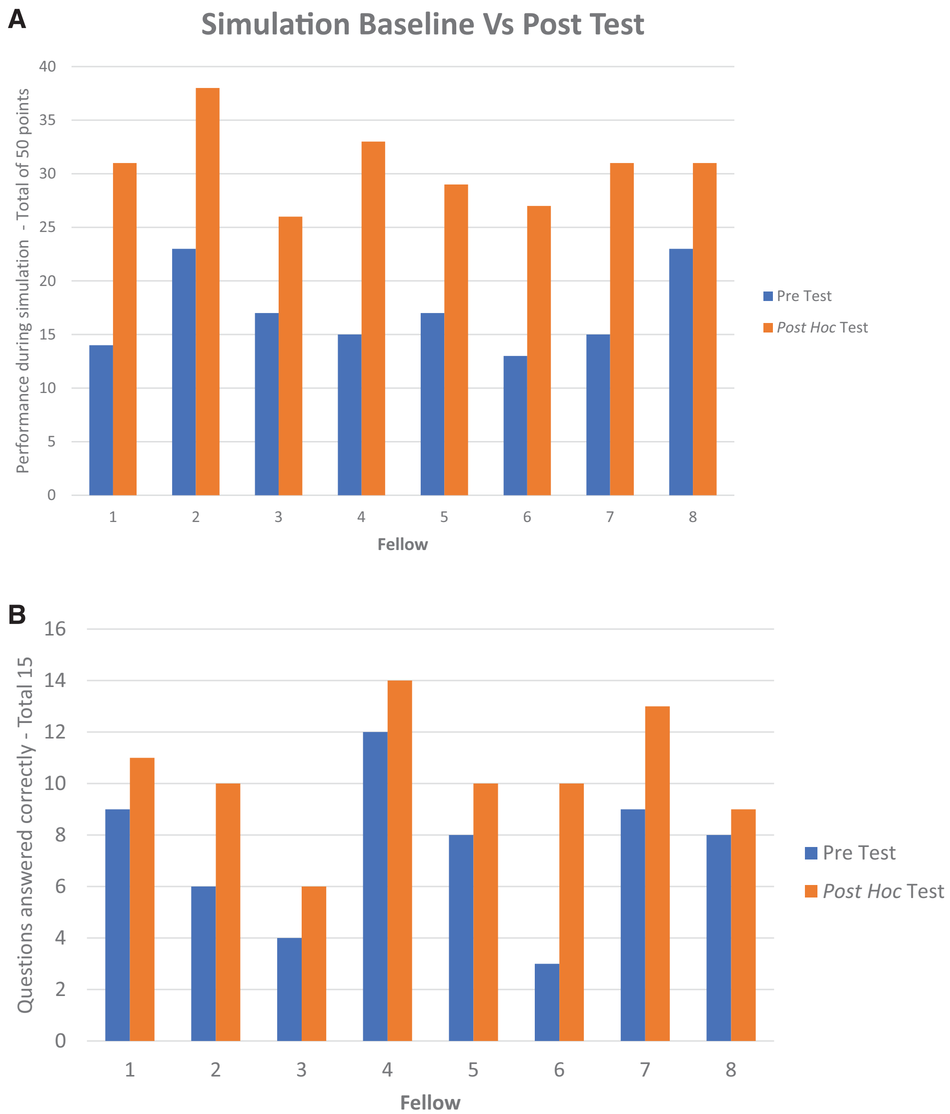

Figure 2. Individual fellow performance scores for (*A*) the multiple-choice question–based knowledge test, and (*B*) the simulation-based competency skill assessment after 2 weeks of training.

education in medical students and residents (19–21).

We postulate that integrating multiple teaching approaches (MCQs, skills training, small group sessions, and RCDP) with high-fidelity manikin simulation led to these improvements. Our curriculum has aimed for comprehensive coverage of respiratory failure and MV management. Incorporating a high-fidelity simulation and RCDP allowed for assessing cognitive and hands-on competencies, including real-time critical thinking during a simulated crisis of the COVID-19 pandemic and effective communication with MV team members.

Strengths and Limitations

The study has several strengths. First, the content and test tools were assessed for internal validity, internal consistency, and reliability per competencies based on the American Board of Internal Medicine pulmonary and critical care certification examination questions listed in Table 1.

Second, we used a curriculum design that included a high-fidelity simulation modality during the COVID-19 pandemic, allowing for the immediate use of knowledge and skills acquired. Furthermore, our approach allowed for retention via diverse learning styles using summative and formative assessments, using set criteria of cognitive-skill competencies and open-ended learner-led discussions, respectively (22, 23). Third, we used a replicable platform that could be added to other training centers with similar equipment. Specifically, using Laerdal Learning Application (LLEAP) allows for replication with limited trainer input, as LLEAP curriculum files use branching sequence pathways in each scenario, with tester prompts based on trainee responses (*see* Appendix F educational simulation session PowerPoint walkthrough). Fifth, to allow for identical training of future trainees, our didactic video component uses the Edpuzzle platform to add future trainees to our existing didactic video library and topics tested in our curriculum (Appendix G). Sixth, we limited our posttest period to 2 weeks. We believe this is a realistic time frame, as PCCM fellowships typically have limited boot camp time frames before fellows start individual rotations. Finally, our blended approach could be replicated in future pandemic periods if such a necessity arose.

Several limitations to our study influence the interpretation of the results. First, a small sample size ($N = 8$) and a single institution limit the study's power, in addition to potentially increasing variability and margin of error. As this is a pilot study looking at the efficacy of our blended teaching curriculum, we opted to limit our testing to new trainees to prevent any bias introduced through experience already accumulated in fellowship. Second, training our PCCM fellows in MV management during the height of the COVID-19 pandemic was a priority. As a result, we did not have a randomized control group that did not undergo this curriculum. It is unknown if the equivalent 2-week posttest results could be achieved with experiential learning alone. However, this is rather unlikely, as our learners did not yet gain significant ICU experience by the 2-week posttest period. Third, this study may be prone to referral bias and experimenter expectancy, as some of the instructors of this curriculum were also part of its development team. Grading was established before implementing the curriculum to standardize criteria for meeting elements of the competency checklist and minimize this bias. Fourth, test–retest bias is possible, as the same test questions and case scenarios were used in pre- and posttests. We aimed to minimize this effect with our 2-week posttest washout period and by immediately collecting all completed knowledge tests, not providing the test answers, and randomizing question-and-answer choice order. Finally, the replication of this curriculum requires significant investment in equipment. Despite high-fidelity simulation becoming more popular, not all fellowship programs have access to simulation programs, which can limit the generalizability of this curriculum.

Conclusions

This study demonstrates the feasibility of using a blended simulation-based curriculum to improve medical knowledge and skills related to MV for PCCM fellows. We hope for further validation of this curriculum by other PCCM fellowship training programs to provide additional generalizability.

Author disclosures are available with the text of this article at www.atsjournals.org.

REFERENCES

1. Accreditation Council for Graduate Medical Education. ACGME program requirements for graduate medical education in pulmonary disease and critical care medicine. 2001 [updated 2020 Jul 1; accessed 2021 Nov 1]; pp. 1–20. Available from: https://www.acgme.org/globalassets/PFAssets/ProgramRequirements/156_PCCM_2020.pdf?ver=2020-06-29-162350-7872020&ver=2020-06-29-162350-7872020.

2. Brescia D, Pancoast TC, Kavuru M, Mazer M. A survey of fellowship education in mechanical ventilation [abstract]. *Chest* 2008;134:62S.

3. Issenberg SB, McGaghie WC, Petrusa ER, Gordon DL, Scalese RJ. Features and uses of high-fidelity medical simulations that lead to effective learning: a BEME systematic review. *Med Teach* 2005;27:10–28.

4. Alluri RK, Tsing P, Lee E, Napolitano J. A randomized controlled trial of high-fidelity simulation versus lecture-based education in preclinical medical students. *Med Teach* 2016;38:404–409.

5. Morgan PJ, Cleave-Hogg D, Desousa S, Lam-McCulloch J. Applying theory to practice in undergraduate education using high fidelity simulation. *Med Teach* 2006;28:e10–e15.

6. Heitz C, Brown A, Johnson JE, Fitch MT. Large group high-fidelity simulation enhances medical student learning. *Med Teach* 2009;31:e206–e210.

7. Gordon JA, Hayden EM, Ahmed RA, Pawlowski JB, Khoury KN, Oriol NE. Early bedside care during preclinical medical education: can technology-enhanced patient simulation advance the Flexnerian ideal? *Acad Med* 2010;85:370–377.

8. Owen H. Early use of simulation in medical education. *Simul Healthc* 2012;7:102–116.

9. McCoy CE, Menchine M, Anderson C, Kollen R, Langdorf MI, Lotfipour S. Prospective randomized crossover study of simulation vs. didactics for teaching medical students the assessment and management of critically ill patients. *J Emerg Med* 2011;40:448–455.

10. Maddry JK, Varney SM, Sessions D, Heard K, Thaxton RE, Ganem VJ, *et al.* A comparison of simulation-based education versus lecture-based instruction for toxicology training in emergency medicine residents. *J Med Toxicol* 2014;10:364–368.

11. Raleigh MF, Wilson GA, Moss DA, Reineke-Piper KA, Walden J, Fisher DJ, *et al.* Same content, different methods: comparing lecture, engaged classroom, and simulation. *Fam Med* 2018;50: 100–105.

12. Hunt EA, Duval-Arnould JM, Nelson-McMillan KL, Bradshaw JH, Diener-West M, Perretta JS, *et al.* Pediatric resident resuscitation skills improve after "rapid cycle deliberate practice" training. *Resuscitation* 2014;85:945–951.

13. Kutzin JM, Janicke P. Incorporating rapid cycle deliberate practice into nursing staff continuing professional development. *J Contin Educ Nurs* 2015;46:299–301.

14. Powers S, Claus N, Jones AR, Lovelace MR, Weaver K, Watts P. Improving transition to practice: integration of advanced cardiac life support into a baccalaureate nursing program. *J Nurs Educ* 2019;58:182–184.

15. Crocker LM, Algina J. Introduction to classical and modern test theory. Orlando, FL: Holt Reinhart Winston; 1986.

16. National Research Council. Knowing what students know: the science and design of educational assessment. Washington, DC: The National Academies Press; 2001.

17. Kelley TL. The selection of upper and lower groups for the validation of test items. *J Educ Psychol* 1939;30:17–24.

18. Pulukuri S, Abrams B. Incorporating an online interactive video platform to optimize active learning and improve student accountability through educational videos. *J Chem Educ* 2020;97: 4505–4514.

19. Spadaro S, Karbing DS, Fogagnolo A, Ragazzi R, Mojoli F, Astolfi L, *et al.* Simulation training for residents focused on mechanical ventilation: a randomized trial using mannequin-based versus computer-based simulation. *Simul Healthc* 2017;12:349–355.

20. Schroedl CJ, Frogameni A, Barsuk JH, Cohen ER, Sivarajan L, Wayne DB. Impact of simulation-based mastery learning on resident skill managing mechanical ventilators. *ATS Scholar* 2021;2:34–48.

21. Leigh Y, de Elia C, Krishna M, Taylor L, Morales R, Kellogg B, *et al.* Simulation training on mechanical ventilation using a high-fidelity ventilator mannequin for residents and respiratory therapists. *Int J Respir Pulm Med* 2019;6:108.

22. Keegan RD, Brown GR, Gordon A. Use of a simulation of the ventilator-patient interaction as an active learning exercise: comparison with traditional lecture. *J Vet Med Educ* 2012;39:359–367.

23. Singer BD, Corbridge TC, Schroedl CJ, Wilcox JE, Cohen ER, McGaghie WC, *et al.* First-year residents outperform third-year residents after simulation-based education in critical care medicine. *Simul Healthc* 2013;8:67–71.