A Flipped Classroom Pilot in Neonatal Mechanical Ventilation

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ABSTRACT

Background: Pediatric residents frequently manage critically ill neonates but have limited systematic training in mechanical ventilation (MV). Competing demands, varying learner levels, and topic complexity contribute to inconsistent education. A blended learning approach may be ideally suited to achieve meaningful learning but has not been described for this topic and learner.

Objective: To design, implement, and evaluate a flipped classroom for pediatric residents in neonatal MV.

Methods: We used Kern's six-step framework for curricular development to create a flipped classroom curriculum in neonatal MV. Individual prework included interaction with six prerecorded animated whiteboard videos, while in-person learning occurred in small groups at the bedside of a ventilated infant. A mixed-methods evaluation included surveys, quantitative knowledge test scores (before, immediately after, and six months after course completion), and qualitative analysis of participant focus groups.

Results: Twenty-six learners participated in the curriculum. Mean knowledge test scores rose and were sustained after course completion (51% baseline, 82% immediate posttest, 90% retention; $P < 0.001$). Learners identified various design elements, technology affordances, and instructor factors as meaningful, and they identified unexpected impacts of the curriculum beyond knowledge acquisition, including effects on professional identities, interdisciplinary communication skills, and contribution to the culture of safety.

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Conclusion: This curriculum aligned with resident roles, was meaningful to learners, and led to long-term increases in knowledge scores and access to quality education; flipped classroom design using meaningful learning theory and leveraging animated whiteboard technology may be a useful strategy for other highly complex topics in graduate medical education.

Keywords:
neonate; blended learning; technology-enhanced learning; graduate medical education; mechanical ventilation education

The American Board of Pediatrics (ABP) has identified that critical care knowledge and skills are not simply for intensivists, stating in core Entrustable Professional Activity 10 for General Pediatrics that "managing patients with acute and severe illness is a core activity of a pediatrician" (1). The ABP outlines that residents are expected to become increasingly entrustable to achieve this goal by knowing when to seek help and consultation and by developing effective communication skills for critically ill patients. Although pediatric residents are not expected to become experts in invasive neonatal mechanical ventilation (MV), they are expected to have sufficient knowledge to safely care for neonates with respiratory failure. Because clinical exposure is not enough to ensure competency in critical care skills (2), high-quality education in these domains is imperative.

Learners in graduate medical education (GME) frequently view training in MV as insufficient (3–6). Factors leading to variable or absent curricula include ambiguities in curricular specifications from governing bodies; inconsistent ventilator nomenclature (7, 8); the high basic science education needed for clinical application (9, 10); and, in the neonatal intensive care unit (NICU), the unique neonatal pathophysiology and needs of neonates (11, 12). Duty-hour restrictions and varying resident schedules further challenge the delivery of effective, equitable education.

To meet the needs of both patients and learners, we aimed to develop and evaluate a systematic approach to neonatal MV education tailored to pediatric residents. An integrated approach proximal to the clinical rotation was necessary, yet faculty time required to comprehensively train each group of rotating residents was too great to be sustainable. To balance these competing demands, we developed a pilot a flipped classroom (FC) curriculum to train pediatric residents in concepts and application of neonatal MV during their NICU rotation and then assessed the curricular impact on learners' attitudes and knowledge.

METHODS

Using Kern's six-step framework for curricular development (13), we aimed to design, implement, and evaluate a technology-enhanced FC curriculum for a pathophysiology-based approach to both conventional and high-frequency ventilation for pediatric residents. Participation was required during the curriculum but voluntary for the focus groups. This study was deemed exempt by the Mayo Clinic Institutional Review Board.

Problem Identification

The previous approaches to teaching and learning MV in our NICU were heterogeneous, instructor dependent, disconnected from the bedside, and variable in depth and breadth inversely with unit acuity. In iterative discussions, our author group conceptualized the ideal curriculum as one that would improve learners' abilities to communicate about a neonate's respiratory status as well as their ability to be able to propose and defend a potential next step in ventilator management. The critical components included neonatal respiratory pathophysiology, guiding principles and lexicon of assisted ventilation, risks and benefits of invasive MV, and defining and assessing the adequacy of MV in neonates.

General and Targeted Needs Assessment

Review of the literature identified few resources for training pediatric residents in neonatal MV. Although Aurora and colleagues described their approach to training in conventional ventilation (4), their curriculum did not include training in high-frequency ventilation. We surveyed pediatric residents at our institution in June 2020, so that reported views reflected the highest level of training for that academic year. We found that despite broad career intent, 96% of residents reported that knowledge and skills in neonatal MV were either "essential" or "quite important" to them. However, only 32% of residents reported more than slight satisfaction with their exposure to MV training. Nearly 60% of residents surveyed reported a desire for between 2 and 5 hours of training, and another 30% desired >5 hours of training.

Goals and Objectives

Guided by the differences between the existing curriculum, ABP training guidance, and the learners' reported needs, content experts in neonatal MV (J.E.B., W.A.C.) iteratively developed learning objectives, which were reviewed by experts in GME (S.C.M., W.A.C., D.J.K.) to ensure relevance and appropriateness for this curriculum's target audience (*see* Appendix E1 in the data supplement).

Educational Design Strategies and Implementation

The course was designed with attention to best practices in FC design and using the conceptual framework of meaningful learning theory (14, 15), which posits five aspects of educational design to shift beyond recall and move toward knowledge application and problem solving. In meaningful learning, learning is active, intentional, authentic, constructive, and cooperative. FC is a modality increasingly used in GME (16) that positions independent learning activities before active, face-to-face learning. Through required prework, FC can transform in-person activities from lower level education strategies, such as remembering and understanding via lecturing, to higher level ones, such as analysis and application via discussion and problem solving (17). Independent prework also may decrease faculty time required to repeatedly teach foundational topics to sequential groups of learners.

To create meaningful independent learning experiences, we leveraged technology to optimize dual-channel processing theory, as humans have separate processing systems for auditory and visual information (18, 19), and to increase accessibility. Course modules were created using Explain Everything (Promethean) technology, which afforded customized animation and concurrent narration, and housed it in the learning management system Blackboard Collaborate (Blackboard Inc.). Each of the six modules

Table 1. Independent learning: animated whiteboard modules

Respiratory mechanics in the neonate
The ventilator as a tool
Oxygenation and ventilation in assisted ventilation
Reading the ventilator
Augmenting the exam: blood gases and X-rays
Putting it all together

(Table 1), mapped to course objectives, included concurrent audio and visual effects in an animated whiteboard style and lasted <15 minutes. Individual modules emphasized the integration of basic science with practical skills (e.g., linking the mechanical concept of compliance with an animated pressure–volume loop on a conventional ventilator screen). Patient cases were used to illustrate key concepts throughout all modules, and both still and animated images of ventilators used in our NICU were incorporated throughout (a whiteboard example is available in Video E1 in the data supplement). To allow spaced learning over time, learners were invited by e-mail to engage with this material beginning two weeks before their NICU rotation and were expected to have watched all videos (a total of 90 min) by the end of their first week.

The face-to-face portion of the FC emphasized learner engagement in problem solving and application at the bedside. Learners were instructed to come to each of two 30-minute guided learning sessions with an answer to the question "What are you still wondering about regarding neonatal mechanical ventilation?" Sessions were conducted in groups of two or three at the bedside of a neonate on a mechanical ventilator and led by a neonatology fellow. Fellows were instructed in use of techniques such as spaced retrieval, reflection, and quizzing within the bedside learning sessions to deepen learning. Occasionally, there was no neonate in the NICU on the ventilator of interest that day; in these instances, the in-person setting included role play and deliberate practice in communicating status updates and proposing changes in simulated cases of ventilated neonates.

Mixed-Methods Evaluation Design

We used both quantitative and qualitative approaches to learner assessment and program evaluation. Although test scores were tied to each learners' identity, we believed that anonymity was critical to obtaining robust survey data regarding learner opinions regarding course design, implementation, and impact. Statistical analyses were conducted in R (https://www.r-project.org/). *P* values <0.05 were considered to indicate statistical significance.

Quantitative. Learners completed anonymous pre- and postcourse Likert-type surveys of baseline and postcourse views of topic importance, confidence in ventilator management, perceived value of the curriculum and FC approach, and postgraduation plans. Unipolar five-point Likert-type scales were used to assess learner reactions, such as perceived topic importance, satisfaction with the quantity of content, and confidence in MV skills (i.e., anchors included not confident,

slightly confident, moderately confident, quite confident, and extremely confident), and responses were analyzed using unpaired *t* tests (20, 21). Bipolar five-point Likert-type scales were used to determine the degree of learner agreement with satisfaction related to quality and structure of content.

Learners also completed three knowledge tests during the curriculum: immediately before the independent learning, during the final week of their NICU rotation, and then six months later. As we could not find an existing knowledge instrument for neonatal MV sufficient for our intended use, we created three independent knowledge tests; each test was distinct from prior tests and included six multiple choice questions, each grounded in a patient case and requiring application of learned neonatal physiology principles. Validity evidence for this knowledge assessment was analyzed according to Messick's unifying theory of validity (22). Sources of validity include content evidence (mapping to curricular objectives, question writing by subject-matter experts), response process (pilot testing among six academic neonatologists with subsequent test revisions, explicit description of test purposes to learners), and internal structure (data quality control through the learning management system and precourse knowledge test Cronbach's $\alpha = 0.71$) (23). Within-learner knowledge test changes over time were analyzed using repeated measures analysis of variance (ANOVA).

Qualitative. One year after curricular completion, we invited learners to participate in a focus group discussion to understand their course experiences. Participation in the focus group was on a volunteer basis only; no incentives were provided for participation. Using a grounded-theory approach (24), we aimed to evaluate which aspects of course design and delivery learners found meaningful. One-year follow-up was chosen to allow additional clinical experience where knowledge and skills in MV could be applied and to increase the likelihood that enduring aspects of the curriculum would emerge. The groups were moderated by a trained facilitator (D.J.K.), who had no personal or educational relationships with the learners. To remind learners of the MV videos, each focus group began by replaying a 3-minute video clip from one of the modules. The session was audio recorded and transcribed using deidentified participant labels using Rev.com technology. Two reviewers (S.C.M. and D.J.K.) used open and axial coding and a constant-comparison technique, iteratively identifying initial themes and subthemes emerging from the data.

RESULTS

All postgraduate year 1 (PGY-1) and PGY-2 pediatric residents at our institution (13 PGY-1 and 13 PGY-2 residents) completed the curriculum during the 2020–2021 academic year. Six animated whiteboard modules were developed and accessed by all residents at least once. The total time commitment for most residents was 2.5 hours, though there was unlimited access to the online modules for two weeks before and throughout the NICU rotation. The total in-person instructor time commitment was 1 hour per month.

Learner Assessment

Twenty-six precourse and 25 postcourse anonymous surveys were collected. Residents reported that knowledge and skills in infant MV were either quite important (46%) or essential (54%). Most reported a total time commitment (including watching, annotating or note taking, pausing to answer questions, and

revisiting notes taken during the modules) of 1–2 hours (44%) or 2–5 hours (40%) during the curriculum. Despite the time commitment, all residents either agreed or strongly agreed that the modules were a good use of their time, and 96% were satisfied or extremely satisfied with the amount of material presented in the modules. All either agreed or strongly agreed that they benefited from self-directed, guided learning early in the rotation, and all either agreed or strongly agreed that FC is a good way to learn complex topics such as the approaches to neonatal MV (*see* Appendix E2). Mean confidence scores for managing neonates on both conventional and high-frequency ventilators increased significantly after the curriculum, from 1.7 (standard deviation [SD], 0.8) to 3.3 (SD, 0.6) ($P < 0.001$) and from 1.2 (SD, 0.4) to 2.6 (SD, 1.0) ($P < 0.001$), respectively (unpaired two-sided t test) on a five-point Likert-type scale.

Twenty-six leaners completed the baseline precourse and postcourse tests, and 24 learners completed the knowledge retention test. Mean knowledge test scores increased significantly with training and (precourse mean 51% [SD, 22%]; postcourse mean 82% [SD, 14%]) and notably were sustained six months later (retention score mean 90% [SD, 18%]) ($P < 0.001$, repeated-measures analysis of variance) (Figure 1).

Program Evaluation

Eight residents agreed to participate in the virtual focus group in the learner-centered evaluation; two sessions with four learners each were conducted. Major themes that emerged related to curricular elements that facilitated meaningful learning (including various curricular design elements, technology affordances, and instructor factors) and the curricular impact on the learners and learning environment (including effects on professional identity formation, interdisciplinary communication, and the contribution to the culture of safety) (Figure 2). Quotations below are identified with group (G) and participant (P) number.

Curricular Elements Contributing to Meaningful Learning

Instructional design principles. Learners identified numerous design features of the curriculum as important. In each

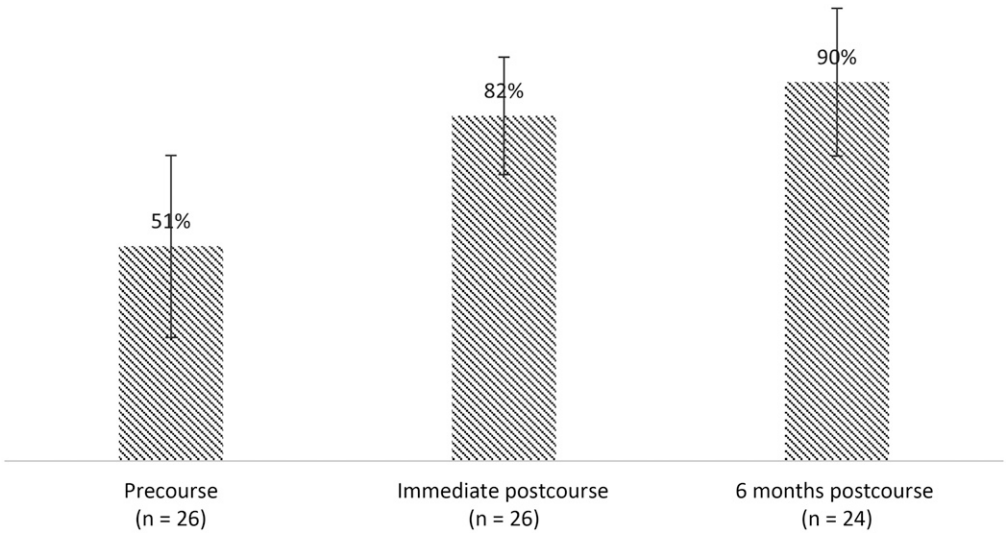

Figure 1. Mean knowledge scores throughout the curriculum. Error bars indicate standard deviation.

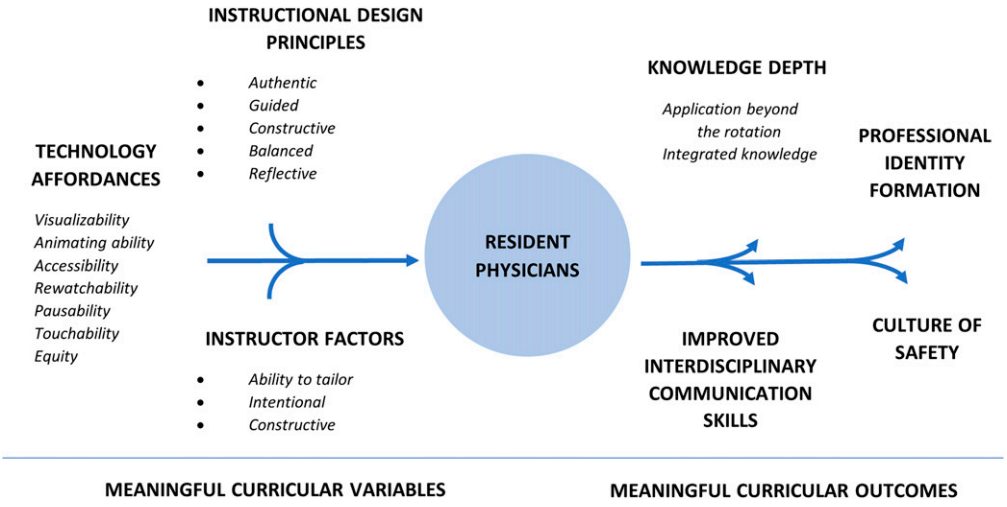

Figure 2. Focus group evaluation: curricular inputs and outputs perceived as meaningful by learners in the neonatal mechanical ventilation curriculum.

focus group, learners universally reported that the independent work was easily completed. They appreciated attention to appropriate cognitive load and emphasized the importance of guided learning during independent prework:

> At least for me personally, it was scary, so harder to just tackle on my own. And so, having somebody guide us through that was really helpful, breaking it down into small step-by-step pieces. (G1P1)

Learners described the importance of finding the suitable type and amount of foundational knowledge. Residents recalled previous sessions as less meaningful when knowledge was not viewed as level appropriate, noting challenges due to large expert–novice differences.

> The kind of on-the-fly vent teaching on the floor, whether it's from attendings or fellows, it's just one of those things that feels like you forget what it's like not to know anything. And so that teaching ends up being more advanced almost always when it's just kind of off-the-cuff. (G2P4)

Residents noted features that allowed active participation (such as note taking) and reflection (prompts encouraged users to pause the videos and answer questions or explain concepts to themselves):

> I think the other thing was when she would say pause for a moment, so you could actually reflect on what did I hear before you move on. (G1P4)

A common theme identified by residents was believing that the required course work was related to their authentic work in the NICU. Learners highlighted the critical need to relate pathophysiology to patient care:

> One of my favorite parts is that she showed us our actual ventilator, like the one that we use in the NICU and in the PICU [pediatric intensive care unit]. … I think we learn a lot about the concepts of PEEP [positive end-expiratory pressure] and FRC [functional residual capacity] and everything like that, but no one had ever done instruction specifically with our ventilator before … so it really helped me actually understand that patient's physiology better than anything else, and I think it helped me be a better doctor to that patient. (G1P2)

Technology affordances. Learners identified several technology affordances (19) within the animated whiteboard component that they deemed useful, including visualizability, animating ability, rewatchability, and pausability.

> Being able to see it written out as though someone was actually standing in front of you and teaching you. (G1P4)

> You could go back and rewind when you wanted to. (G1P2)

They noted the ability for just-in-time teaching both proximal to the rotation and even later in residency training. Learner reported that the prework allowed increased flexibility and even described the contribution to equitable education by improving access to quality learning resources.

> I saw [the videos] for the first time during my first NICU block as an intern. And then when I went back as a second year, that was the first thing I did, was rewatch them each several times. (G1P1)

Instructor-specific factors. Important instructor factors were the ability of the bedside instructor to be able to uncover the learner agenda, assess baseline knowledge, and ask probing questions.

> I think some people come in and they have this is what I teach and this is what I teach every time. It doesn't matter what people are coming to it with. But [the instructor] tailored it specifically to the knowledge level of everyone. (G1P2)

Impact of the Curriculum on Learners

Impact on professional identity. Residents noted linked knowledge of MV with increased identity as the first-line clinician caring for the infant.

> If someone's changing a vent, even if it's not me, I need to know how that's going to affect my patient. What do I need to be looking out for? If you don't understand the basics, you can't even start to challenge yourself to think about the bigger picture. So, I think that this is a really reasonable thing to be expected of learners who are going to be responsible for patients on vents. (G2P2)

Impact on knowledge depth and translation. Learners emphasized their desire to reduce illusions of knowledge and equated knowledge of how physiology informs clinical application with increasing expertise.

> I feel like it's easy to just get by with vents and pretend like you know what you're talking about and listen to what the RTs [respiratory therapists] are saying and then make those proposed changes. But you're not really learning what's actually going on behind it. (G2P1)

Residents also variably reported the influence of the curriculum on other inpatient rotations.

> But I went back, I was in the PICU twice afterwards so I think I actually had the most relevance for my PICU rotations. (G1P2)

Impact on communication skills. Residents described the curricular impact on their communication skills with families and within the multidisciplinary team.

> And I think that by reviewing each of the components of what you're seeing on the ventilator, what you're putting in and what you're getting out, and what's unique to that baby, it gave me more confidence on rounds to be able to present the data, but also use my brain to figure out what the next steps were for that patient and their care. (G1P3)

Impact on patient safety. Finally, residents also recognized their own knowledge and skills in MV as contributors to patient safety.

> I didn't have this curriculum when I was an intern, so I learned what an oscillator was because I walked in one morning and they were like, we put your patient on an oscillator overnight. And I was like, "Great. What is that?" I didn't even know that it was a type of ventilator. And so, I learned what an oscillator did between that and rounds, which I think is actually unsafe. There were

> other people on the unit that understood the oscillator, but I was the person writing orders for the patient and didn't know what it was. (G1P2)

Among focus group participants, residents deemed that knowledge and skill in neonatal MV were essential.

> I think if we agree that NICU rotations are a necessary part of pediatric residency, which I argue that it is, I think then that ventilator education is an essential part of the NICU education and therefore in residency. (G1P3)

DISCUSSION

Pediatric residents remain first-line providers in many academic NICUs who care for critically ill neonates. Although the purpose of general pediatrics residency is not to develop intensivists, it is to develop physicians who are capable of managing, stabilizing, and triaging sick pediatric patients. Similarly, residents are expected to "demonstrate effective communication skills in managing a severely ill patient" and "know when to seek help" (1), skills that are developed only by deliberate and repeated care of critically ill patients. By leveraging animated whiteboard technology and FC design, we implemented an integrated approach to neonatal MV curriculum that aligned with current pediatric resident roles, was acceptable and meaningful to learners, and led to long-term increases in knowledge scores and access to high-quality education. Importantly, learners described curricular impacts beyond increased ventilator knowledge alone, namely, the influences of knowledge acquisition on their professional identities as physicians, communication within the multidisciplinary team, and role in patient safety.

The mixed-methods, learner-centered evaluation provides insight into curricular features that may be important in designing future curricula in complex topics such as neonatal MV. In meaningful learning, emphasis is creating active, intentional, authentic, collaborative, and constructive curricular elements. Features of both independent and small-group work were seen as impactful, with residents describing both sides of the FC as active and intentional. Integrating basic science knowledge into clinical medicine in the prework, bedside teaching, and assessment tools was seen as facilitating authenticity. Residents did not emphasize the importance of collaboration but instead stressed the impact of guided learning experiences tailored to the knowledge levels. This is consistent with knowledge that minimally guided approaches work well only when learners have "sufficiently high prior knowledge to provide internal guidance" (25). Such constructive elements were incorporated only when the foundational knowledge was raised via the necessary prework, in the bedside learning sessions.

In the independent learning part of this FC, the use of technology-enhanced learning also contributed to meaningful learning experiences. Our approach to technology-enhanced learning was guided by Bower's approach, which emphasizes that selection of learning technologies should arise from the desired learning outcomes (19). We sought a technology that could leverage dual-channel processing theory; guide novice learners systematically through complex concepts; and enhance modality, personalization, and signaling effects in a single learning experience. Animated whiteboard technology allowed for these features, especially in concurrent audio and visual representation of content, customized animation and transitions, and facile and varied content

representation (such as incorporating images, videos, animated algorithms, and signaling text and symbols). In the evaluation, learners confirmed that content visualizability, animating ability, rewatchability, and pausability made the prework seem guided, interactive, and ultimately constructive.

Several studies have raised concerns about the utility of FC in GME, noting poor prework completion rates (26) or learner concerns about the preparation time required in the FC (27). In contrast, all learners in the present study watched all required module, and all agreed that they contributed to meaningful learning; focus group participants universally reported the expected prework was reasonable and even "not hard" (G1P1). This may be because expectations were provided to learners two weeks ahead of the clinical rotation, allowing residents to incorporate these tasks into their individual learning plans despite busy clinical schedules.

Strengths of the study include adherence to Kern's curricular development framework and grounding in the conceptual framework of meaningful learning by way of FC design. Evaluation strengths include limited learner attrition, incorporation of long-term retention testing, and delayed and robust focus group facilitation to assess the longitudinal curricular impact. Limitations of this study include a focus on reactions and knowledge data. In addition, focus group responses are limited to those willing to voluntarily participate and thus may not represent all learners' viewpoints. Nonetheless, of the 96% of course participants who provided postcourse survey data, all described the topic of infant MV as either quite important or essential. Finally, although neonates were infrequently affected by respiratory failure caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), pediatric residents may have been further motivated to learn principles of MV during this curricular implementation, which coincided with the coronavirus disease (COVID-19) pandemic, because of increased awareness of other types of respiratory failure. Future studies may benefit from assessment of learners' observed or simulated behaviors and the curricular impact on patients. As our evaluation was learner centered, we did not explore the impact of the curriculum on faculty members, which is important when considering the utility and acceptability of novel GME programs.

Conclusions

Tailored, systematic education in neonatal MV using a meaningful learning framework and an FC approach is a feasible approach to teaching this complex topic and may improve learner knowledge and skill. Learners universally valued this education and identified knowledge of MV as critical to their role as resident physicians in promoting safe patient care.

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

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