

Development and Implementation of a Microlearning Curriculum of Physiology Formulas for Postgraduate Clinical Fellows in Pediatric Critical Care Medicine

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ABSTRACT: Postgraduate medical education in clinical settings poses many challenges secondary to the large volume of knowledge to be acquired, competing clinical responsibilities, and fatigue. To address these challenges, a microlearning curriculum using flipped classroom methodologies was created to facilitate the mastering of fundamental physiology formulas by pediatric critical care medicine fellows. Forty physiology formulas were distilled into 5-minute microlearning sessions. Fellows were provided the weekly formula and encouraged to self-study prior to the face-to-face learning. The 5-minute session took place at the beginning of a regularly scheduled clinical care conference where normal values, explanatory diagrams, and board-like questions were discussed. A faculty or fellow facilitator then provided a more in-depth explanation and shared clinical pearls related to the formula. Following the session, an e-mail summarizing the learning points was sent. The curriculum was well received by fellows and faculty. Over 5 years, the curriculum evolved through phases of active development, implementation, minor modifications, transition to a virtual platform, shift to senior fellow-led instruction, and harmonization with other curricular activities. Engagement and sustainability were addressed with a fully flipped classroom, where senior fellows served as teachers to junior fellows. Microlearning in a multimodal manner is an excellent method for teaching busy postgraduate clinical trainees fundamental physiology formulas that underpin pediatric critical care decision-making. The gradual transition from individual learning to a flipped classroom taught by peers with faculty support was well tolerated and consistent with adult learning theories. The transition was essential to ensure the sustainability of the curriculum.

KEYWORDS: physiology, graduate medical education, pediatric critical care medicine

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Introduction

Postgraduate medical education in clinical settings poses many challenges secondary to the large volume of knowledge to be acquired, competing clinical responsibilities, growing regulatory and administrative tasks, and fatigue. The traditional 60-minute didactic lecture has remained the cornerstone in many postgraduate training programs but may not be optimal for current physicians-in-training. Adequate resources are needed to ensure the learner is not interrupted by calls, texts, or pages during the 1-hour session, as learning is improved with protected learning time.¹ Additionally, postgraduate medical trainees in acute care specialties may have difficulty focusing on the entire session secondary to sleep deprivation, stress state, and concern of missing out on patient care.² Thus, it has become increasingly challenging to have effective one-hour teaching sessions for acute care postgraduate trainees.

To address these barriers, many curricula have been developed around the concept of microlearning, which is the process of acquiring knowledge through small chunks of information used to meet a specific learning outcome.³ Its potential advantages include improved learning volume and retention, enhanced procedural performance, increased learner satisfaction, and better engagement.^{3,4} The method is well suited for

the postgraduate clinical fellow in the acute care setting given the limited protected learning time, the need for rapid acquisition of critical knowledge, and ensuring learner satisfaction.

Further, there has been a movement in post-graduate medical education to recognize that the traditional didactic method is not always the best for the adult learner.⁵ Thus, the concept of the “flipped classroom” was developed, in which students learn didactic material independently ahead of time and then take part in “face-to-face” time for more engaging and active learning strategies.⁶ This style of learning has found traction among pediatric fellows and educators, with the flipped classroom approach preferred by some over the traditional didactic approach.⁷

All pediatric specialties rely upon physiologic knowledge for day-to-day decision-making. This is particularly true in acute care fields such as critical care medicine, neonatology, emergency medicine, and cardiology, where physiologic derangements present in real-time and need to be rapidly corrected. Further, the ACGME expects fellows to “demonstrate competence in their knowledge of physiologic principles.”⁸ Thus, we created microlearning curricula using flipped classroom methodologies designed to facilitate the mastering of fundamental physiology formulas for pediatric critical care medicine



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fellows. We describe the experience of developing and implementing the curricula and share the barriers to its implementation while offering solutions to ensure sustainability.

Methods

The curricula were developed from 2018 to 2023. The foundation of the fundamental physiology microlearning curriculum was established from a 1-hour didactic lecture on respiratory physiology historically given yearly to pediatric critical care medicine fellows. While the didactic lecture was well received by the learners, the amount of information presented in a single session was large and challenging to retain. Thus, the didactic lecture evolved over time to include concise, high-yield respiratory formulas that can be easily used while providing direct patient care. The respiratory formulas served as the beginning of the full physiology formula microlearning curricula, which is outlined in Table 1, with formulas provided in the Supplemental Appendix.⁹ The subsequent yearly phases are described below and delineated in Table 2. There were no human study subjects on which individual data was collected, and thus there was no requirement for ethics approval or written consent.

Phase 1: 2018 to 2019 (Year 1)—Implementation and Active Development

One physiology formula and accompanying graphic representation were e-mailed at the beginning of the work week to all pediatric critical care medicine fellows and faculty. A hard

copy of the weekly formula was printed and placed on the fellows' office door as a visual cue. Fellows were instructed to self-study over the next 4 days and faculty were encouraged to incorporate the weekly formula into their bedside teachings throughout the week. To facilitate faculty teaching during the week, they were provided a written description of the weekly formula, its normal values, and an associated clinical pearl. The microlearning physiology lesson was then embedded within a standing weekly conference near the end of the week, "bedside teaching rounds." During the first 5 min of the conference, first-year fellows stated the weekly formula, and then second-year fellows further defined the formula along with normal values, followed by a third-year fellow using the formula to answer a board-like question on a dry-erase board. To conclude the exercise, a faculty member summarized the formula and provided one associated clinical pearl. The following day, the formula, along with a written description, normal values, visual aid, clinical pearl, and answer to the board-like question, was e-mailed to the fellows and faculty for their future reference.

After respiratory formulas, cardiac formulas and associated pearls and board-like questions were developed progressively throughout the year. This was followed by formulas in flow and resistance, perfusion pressures, hematology, nephrology, and fluid and electrolytes. This resulted in the teaching and review of approximately 40 formulas throughout the first year of implementation. A review at the end of the academic year was completed using a "jeopardy" style approach of physiology formulas, with fellows versus attendings. Nonstructured verbal feedback solicited from fellows and faculty throughout the year

Table 1. Physiology formula curriculum outline.

Curriculum components	E-mail weekly formula	Formula posted on fellows' office door	Fellow self-study of formula	Five-minute microlearning module	Follow-up e-mail	
Curriculum content	40 physiology formulas	Written explanation per formula	Formula visual aids	Formula board review questions	Interactive reviews by faculty	Formula clinical pearls
Microlearning module structure	First-year fellow stated formula	Second-year fellow provided normal values		Third-year fellow used a formula to answer board-like question	Faculty reviewed the formula and provided a clinical pearl	

Table 2. Curricular modifications per year.

	2018 to 2019	2019 to 2020	2020 to 2021	2021 to 2022	2022 to 2023
Formulas	40 formulas taught	More renal formulas added	Removed select formulas	Removed select formulas, added further statistics	40-50 formulas taught
Teaching individuals	PTW	PTW, JSB, and occasional other faculty	TDM, PTW, ASG, JSB, occasional other faculty	Senior fellows with the support of TDM, ASG, PTW	Senior fellows with the support of ASG
Curriculum modifications	Jeopardy session	YouTube links, incorporated into didactic lectures	All virtual, PowerPoint presentations are created for each formula, no posting of formula on the door	Microlearning modules run by fellows with faculty support, Life in the Fast Lane website support added	Hybrid format, modules synchronized to simulation activities and didactics

and at the conclusion of the pilot year was overwhelmingly positive. We also obtained feedback from anonymous written internal program evaluations from the fellows on the overall curriculum that was not specific to the microlearning curriculum of physiology formulas.

Phase 2: 2019 to 2020 (Year 2)—Minor Modifications

During the second year of the physiology microlearning sessions, formulas were further expanded by JSB to include more fluid and electrolytes, nephrology, pharmacokinetic, and ion gap formulas. He led several sessions, and other faculty were invited to lead the weekly discussions. Otherwise, the same formulas, pearls, and board like-questions were used. An effort was also made to incorporate the weekly physiology formula into the standing weekly core didactics, with mixed success. The pre-session e-mails also included YouTube videos explaining the formula concept for learners preferring audiovisual learning modalities.

Phase 3: 2020 to 2021 (Year 3)—Transition to Virtual Platform

In the third year of this curriculum, 2 new team members were added. One took over primary responsibility for teaching and preparatory tasks, with the original member and the other new member sharing responsibility for many of the sessions as a primary teacher, with continued support from a third faculty member. As the COVID pandemic upended in-person medical education, all meetings went on virtually. The curriculum was adapted to still occur within the weekly bedside teaching rounds, which had become a virtual discussion. To compensate for this alternative format, PowerPoint slides were developed for each week's session. The formula continued to be e-mailed out at the beginning of the week along with the postsession follow-up summary e-mail. Given the decreased presence of fellows in their offices, formulas were no longer posted on their office doors. The content of the curriculum was kept the same as the previous year, with a few formulas further culled based on fellow feedback and the addition of formulas apropos to the pandemic (including "R" naught, incidence rates, and prevalence).

Phase 4: 2021 to 2022 (Year 4)—Transition to Senior Fellow-Led Instruction Remained Virtual

The curriculum moved even further into the flipped classroom style, with senior fellows taking responsibility for teaching the formulas to the junior (first- and second-year) fellows, with supervision from 3 core faculty. This was done to better engage senior fellows in content that was no longer novel to them and provide them with opportunities to hone their teaching skills. Fellows adapted the existing PowerPoints from the prior year, adding links to the website "Life in the Fast Lane" to augment the learning process.¹⁰ The content of the curriculum was otherwise the same, with less frequently used

formulas removed based on the fellow's recommendations and supplemented with new ones.

Phase 5: 2022 to 2023 (Year 5)—Harmonization

Senior fellows continued teaching the curriculum via a flipped classroom format. Additional core faculty took on supervisory roles, which involved reviewing fellows' planned teaching sessions in advance, and sometimes teaching themselves if a fellow was unavailable due to clinical duties. Teaching sessions moved to hybrid in-person/virtual platforms, which allowed for excellent participation regardless of faculty and trainee on-site availability. Powerpoint presentations were continued, given the hybrid format, to increase engagement by enhancing the remote learner's virtual experience and to appeal to visual learners. They also allow for outside media to be incorporated into the presentations and succinct summation of key learning points. After feedback from the fellows, all formulas were re-organized to harmonize with other regularly scheduled learning activities, such as standard 60-minute lectures and simulation scenarios (eg, the alveolar minute ventilation formula occurred the same week as a lecture on control of ventilation and a simulation of acute hypercapnic respiratory failure.) In addition, weekly e-mails highlighting the formulas were frequently supplemented with more in-depth reading on physiology from both review and primary sources.

Results

Fellows responded well to the microlearning approach and were very well prepared for the 5-minute in-person lesson each week. Feedback was obtained from anonymous, written, internal program evaluations in which the fellows assessed the overall curriculum, including the microlearning curriculum of physiology formulas. They indicated great satisfaction with the curriculum. One fellow reported this response:

The fundamental physiology equation of the week became an essential part of my weekly education. During busy weeks, we thought we didn't have time to look up these principles even though they are the bedrock upon which we base our care. Making this an explicit component of PICU education, and eventually synchronizing the equations with other educational efforts, forced me to engage with the material in a different way. It enhanced my bedside care and ability to understand the "why" of complex PICU care and patient physiology.—PICU fellow

Further informal verbal feedback elicited by program leadership was equally positive.

Discussion

Barriers and Lessons Learned

In the initial year (2018-2019) of the curriculum, there was substantial excitement and buy-in from the entire pediatric critical care division, including fellows, faculty, and pediatric residents

rotating in the PICU. Attendance of fellows and faculty was excellent. Further, senior fellows and first-year faculty commented that the exercises were extremely useful as an adjunct to their critical care board review process. However, the initial curriculum development and weekly implementation was a large workload for one individual. We do note that our evaluation of the curriculum was informal and nonspecific, pertaining to the entire fellow curriculum. This is a limitation we hope to address in the future with specific evaluations to help us measure effectiveness. Further, comparison of baseline in-service training exams and board exams could be compared to those after the implementation of this curriculum. However, it is unclear how physiology formulas are incorporated into these exams, limiting the use of these scores to measure the effectiveness of this curriculum.

The second year (2019-2020) was much less burdensome since most of the preparatory work for each formula had been completed, aside from the few new additions. The addition of another team member also greatly reduced the work burden on one individual. The YouTube videos were not well received by the fellows, as they felt they were too cumbersome compared to one figure per formula. One of the challenges included coordinating formulas with lectures because some lecturers were from outside the division and not all lectures had a relevant formula.

The third-year (2020-2021) barriers were mostly related to the transition to an online platform with the increased workload required for making PowerPoint slides. It was essential to have increased faculty support. Senior fellows and faculty had by then been exposed to the formulas in 2 prior years, and as the novelty and challenge wore off, they sometimes required encouragement to maintain the same focus as in earlier years.

The fourth year (2021-2022) involved a drastic change with the transition to a fellow-as-teacher approach, with additional planning to allow time for fellows to take on this responsibility in their already busy schedules. Any hesitation was alleviated by pairing each fellow with a faculty member to co-present early in the year, with the transition to increasingly independent teaching over the academic year. The senior fellows did an excellent job educating their peers and helped inject more enthusiasm into the learning process. We also found that the fellow-as-teacher approach directly addressed the major challenge observed in the previous year, which was waning enthusiasm due to senior fellows already having learned the formulas. Few motivators are as potent as educating one's slightly more junior peers.

The fifth-year (2022-2023) finally allowed us to synchronize nearly all formulas with ongoing didactic and simulation activities. This was a frequent request from all trainees over several years. Because the formula curriculum was firmly embedded within our culture, we found that faculty was much more open to the idea that swapping didactics due to scheduling requirements might be detrimental to fellow education. While these swaps still happened on occasion, they were either met with

concurrent swaps of formula and simulation material or else a swap to a much closer date to the original scheduled time. This allowed for all didactic materials to mutually reinforce each other. It did, however, require a good deal of attention to the overall schedule, with one faculty member taking primary responsibility.

Conclusions

Microlearning in a multimodal manner is an excellent method for teaching busy postgraduate clinical trainees fundamental physiology formulas that underpin pediatric critical care decision making. The gradual transition from individual learning to a flipped classroom taught by peers with faculty support was well tolerated and consistent with adult learning theories.⁵ This transition was essential to ensure the sustainability of the curriculum, as well as provide learning opportunities for senior fellows who will be transitioning to faculty. We acknowledge the large, in-advance work burden to create the curricula; however, it became much easier with each passing year as it became a part of our program's identity and as the need for modifications decreased. Engaging senior learners-as-teachers is key to maintaining interest and engagement as novelty wanes. The next steps will be to introduce the curricula at additional institutions and obtain formal quantitative and qualitative data on the acceptance, effectiveness, and sustainability of the physiology formula microlearning curriculum.

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Authors' Contributions

Tanya D. Murtha conducted the study, analyzed the data, drafted the initial manuscript, and reviewed and revised the manuscript. Andrew S. Geneslaw contributed to the design, conducted the study, collected the data, and reviewed and revised the manuscript. J. Scott Baird contributed to the design and conduction of the study and critically reviewed the manuscript for important intellectual content. Patrick T. Wilson conceptualized, designed, and conducted the study, collected and analyzed the data, and reviewed and revised the manuscript. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

Ethical Approval

There were no human study subjects on which individual data was collected, and thus there was no requirement for ethics approval.

Informed Consent

There were no human study subjects on which individual data was collected, and thus there was no requirement for written consent.

Supplemental Material

Supplemental material for this article is available online.

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