Generalists as Clinical Physiologists: Bringing Science Back to the Bedside

Daniel N. Ricotta, MD FHM[1,2], Andrew J. Hale, MD[3,4], Jason A. Freed, MD[1,2], Tara E. Scribner, MD[3,4], Mark L. Zeidel, MD[1,2], and Shoshana J. Herzig, MD MPH[1,2]

[1]Department of Medicine, Beth Israel Deaconess Medical Center, Shapiro Institute for Education and Research, Boston, MA, USA; [2]Harvard Medical School, Boston, MA, USA; [3]Robert Larner MD College of Medicine, Burlington, VT, USA; [4]University of Vermont Medical Center, Burlington, VT, USA.

BACKGROUND: Few generalists engage in basic science research or feel comfortable teaching physiology at the bedside. This may reflect a lack of understanding or confidence teaching physiologic principles.
AIM: To inspire general internists to relearn and teach physiology in clinical practice.
SETTING: An active biomedical research laboratory.
PARTICIPANTS: We educated 67 faculty participants (4 primary care, 59 hospitalists, and 4 other specialties) from 24 medical centers, representing 17 states.
PROGRAM DESCRIPTION: The 5-day course was structured around re-learning basic physiology principles and developing teaching skills. Participants engaged in hands-on experiments through 4 modules using aquatic species, each paired with a physiology content primer. Participants also developed teaching scripts based on their experiments.
PROGRAM EVALUATION: Post-course surveys revealed that 97% felt confident teaching physiology at the bedside, 100% felt the course enhanced their understanding of the mechanisms of disease, and there was a significant improvement in self-reported teaching ability.
DISCUSSION: An immersive, hands-on faculty development course that integrated physiology with clinical decision-making increased participants' comfort level and self-rated ability to teach and incorporate physiology in their clinical work. We believe faculty development is one potential solution to the growing chasm between clinicians and scientists in general medicine.

KEY WORDS: quality improvement; faculty development; mechanistic thinking; comparative physiology.
J Gen Intern Med 36(12):3847–51
DOI: 10.1007/s11606-021-06978-0

INTRODUCTION

Embracing systems-based approaches has propelled general medicine to the vanguard of efforts to improve quality, safety, and value of care. This focus on how we care for patients has also informed how generalists teach, prioritizing healthcare systems and processes[1] and tacitly drawing attention away from foundational physiologic and pathophysiologic principles. This dichotomy is curious, as the integration of basic science into clinical problem solving can improve diagnostic accuracy[2–5] and enhance value-based care by providing a framework for physicians to work through uncertain clinical scenarios.[6] Bringing science to the bedside through research and education has been the bedrock of inpatient general medicine for decades, yet few in the nascent hospital medicine field pursue research and basic science investigation.[7–9]

Applying physiology-based principles to patient care reinforces the mission of general medicine to provide high-quality, safe, and cost-effective care.[3,10] Studying basic science may allow clinicians and learners to adopt new approaches as scientific understanding continues to advance rapidly. Mechanistic thinking helps clinicians ask the right questions[11] and get to the underlying causes of a patient's illness. Finally, the scientific method not only strengthens the ability of clinicians to rigorously test hypotheses about individual patients, but also to read the literature critically, and apply it to the patients they care for. Strategies employed by medical schools to ready physicians to practice high-quality care, however, have focused primarily on health systems science,[12] with increasing reliance on clinical rotations for acquisition of basic science knowledge.

The restructuring of medical schools to start clinical training earlier[13,14] and the vertical integration of basic science education[13] implicitly values clinical work over science. The shift in clinical training is exacerbated by a lack of generalists conducting research (including basic science).[9] Insufficient teaching of physiology in the context of patient care, and few clinician investigators, implicitly widens the erroneous gap between basic science and clinical medicine, and undermines the design of an integrated medical school curriculum. It is no wonder that fewer trainees are interested in basic science research.[15] We believe that fewer residents interested in physiology results in fewer attendings facile with physiologic principles and the cycle spirals. To date little has been done within the field of general medicine to break this cycle.

These concerns prompted us to consider new ways to promote interest in physiology among general medicine clinical faculty. We created a novel faculty development course that merges basic science with clinical decision-making,

Received February 24, 2021
Accepted June 9, 2021
Published online July 8, 2021

aiming to stimulate general internists to incorporate more physiology-based teaching into their clinical practice.

SETTING AND PARTICIPANTS

We educated 67 faculty participants (59 hospital medicine physicians, 4 primary care, 4 other specialties) from 24 medical centers across 17 states in annual courses between 2015 and 2019. Courses all took place at the Mount Desert Island Biological Laboratory (MDIBL), an independent, nonprofit, biological research institution located in Bar Harbor, Maine.

PROGRAM DESCRIPTION

We launched "Teaching Physiology On-The-Fly," a faculty development course for clinical teachers, in 2015 as a collaboration between the Department of Medicine at Beth Israel Deaconess Medical Center (BIDMC) and MDIBL. We chose MDIBL because of its rich history pursuing comparative physiology research and interest in educational programming.[16] We used our own experience and an existing BIDMC residency course (*Comparative Physiology*)[10] as a blueprint to interface hands-on basic physiology experiments, and clinical decision-making. Though we did not pursue a formal needs assessment, the impetus for the course was based on course directors' experience that a lack of comfort and insufficient training were limitations to generalists teaching physiologic principles at the bedside.

The course was structured around 2 main components: Relearning basic physiology principles and developing teaching skills. We used physiology primers, delivered by specialists, to review basic physiology concepts and then solidified concepts through hands-on basic science experimentation. Each primer was partnered with teaching skill development through reflection and debriefing to unpack the skills employed by the facilitator. Each experiment was paired with a clinical conundrum which was solved through the hands-on investigation. Consider the following example:

> A 56-year-old man presents with fevers, chills, and purulent drainage from a diabetic foot ulcer. His vitals reveal fever, hypotension, and tachycardia. Exam is notable for petechiae. Laboratory analysis demonstrates marked thrombocytopenia, lactic acidosis, coagulopathy, and an erythrocyte sedimentation rate (ESR) of 10 mm/h (normal: <25mm/h). Why is the ESR normal? Through a series of experiments, the participants discover that fibrinogen is the single most important factor influencing the ESR, and that the ESR is normal in this case because of low fibrinogen levels in the setting of disseminated intravascular coagulation.

Participants engaged in two of the following physiology modules: hematology, secretory, cardiology, and salt and water homeostasis. To ensure a hands-on experience for all, each module accommodated 3–5 participants and included one to three unique experiments running simultaneously. The four modules ran concurrently, and participants rotated through two modules during the 5 days of the course, spending 2 days on each module and working in teams (Table 1). Each module was structured in the following manner: the first day consisted of exploring clinical dilemmas, forming hypotheses, and conducting experiments, while the second day focused on synthesizing learned information into presentation form, and ultimately into teaching scripts for future use. For example:

> The cardiac physiology group ponders how malignant hypertension results in pulmonary edema. Their hypothesis is that hypertension increases afterload which reduces cardiac output. In their experimental model, the learners explant a bullfrog heart and connect it to a bypass circuit. After collecting baseline stroke volume measurements, the investigators then increase afterload by raising the height of the overflow reservoir. Through this experiment, the learners discover that raising the afterload increases cardiac wall-stress and reduces stroke volume, thereby increasing left ventricular end diastolic pressure, and ultimately manifesting in pulmonary edema. The group then synthesizes their findings into a presentation for other course participants

The cardiac physiology group ponders how malignant hypertension results in pulmonary edema. Their hypothesis is that hypertension increases afterload which reduces cardiac output. In their experimental model, the learners explant a bullfrog heart and connect it to a bypass circuit. After collecting baseline stroke volume measurements, the investigators then increase afterload by raising the height of the overflow reservoir. Through this experiment, the learners discover that raising the afterload increases cardiac wall-stress and reduces stroke volume, thereby increasing left ventricular end diastolic pressure, and ultimately manifesting in pulmonary edema. The group then synthesizes their findings into a presentation for other course participants

The course ended with each participant developing a teaching script based on the physiology explored during the week. These are meant to be used for "on-the-fly" teaching of future learners. Each participant led a teaching session in a small group, observed by course faculty who debriefed the teaching. Other experimental questions incorporated into teaching scripts included:

Table 1 Sample schedule of the *Teaching Physiology on the Fly* Course

Time	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
7	Breakfast					
8		Hands-on physiology experiments	Presentation prep	Hands-on physiology experiments	Presentation prep	Teaching practice
9					Presentations	
10			Presentations			
11					Teaching practice	Closing session
12	Lunch					
1		Experiment wrap-up	Physiology primer	Experiment wrap-up	Teaching practice	
2		Faculty office hours	Outdoor activity	Faculty office hours	Outdoor activity	
3						
4						
5		Physiology primer		Physiology primer		
6	Dinner	Dinner	Dinner	Dinner	Social event	
7	Opening session					
8	Physiology primer					
9	Social event					

How the stool osmotic gap can help diagnose the cause of diarrhea.

What is the physiologic response to a salt or water load?

Why do thiazide diuretics lead to hyponatremia more often than loop diuretics?

Is the hematocrit always 3 times the hemoglobin level?

PROGRAM EVALUATION

We surveyed all participants before and after the course to gauge their confidence, satisfaction, and self-reported skill teaching pathophysiologic concepts. Of the 52 participants who responded to the survey (78% response rate), only 41% of participants were comfortable teaching pathophysiology on the wards before the course, compared to 97% following the course. Similarly, 93% of post-course respondents agreed that understanding pathophysiology was important for patient care, and 100% agreed that the course enhanced their understanding of the mechanisms of disease. We also observed improvements in overall teaching, 58% of participants rated their teaching ability highly based on "above average" (55%) and "high" (3%) responses before the course, compared to 82% (70% above average and 12% "high") following the course. In terms of course satisfaction, 96% reported the course was a "community building experience," 94% felt their "goals were met," and 94% reported they would "recommend the course to a colleague."

The course cost $4000 per participant to cover operating expenses such as laboratory materials, acquiring and handling aquatic species, faculty expenses, and participants' housing and meals for the week.

DISCUSSION

We established a novel faculty development course to reintroduce core physiology principles and inspire general medicine faculty to incorporate teaching mechanisms of disease into clinical practice. We found high levels of satisfaction among course participants who overwhelmingly would recommend the course to a colleague. We also found significant improvements in participant's self-reported teaching ability, specifically incorporation of physiology into clinical teaching, and understanding of mechanism of disease.

One reason we found improvements in confidence teaching physiology may be the integration of teaching skill development with physiology primers. Peer feedback also helped to ensure that teaching scripts were tailored to clinical practice. Another key may be the hands-on experimentation. For example, measuring the cardiac output of an explanted shark heart and plotting a Frank-Starling curve following administration of norepinephrine, dobutamine, or metoprolol allows the learner to connect basic cardiac myocyte physiology with clinical care, offering tangible evidence to otherwise abstract principles.

We believe generalists want to incorporate teaching physiology in clinical practice but often lack the skills and confidence to do so. Consistent with this view, clinicians entered our course with low confidence in their basic physiology knowledge and ability to teach it. It is possible the lack of confidence stems from a general trend in medical training towards systems-based approaches compounded by a faculty recruitment process that does not emphasize research.[17] The changing landscape of medical training and lack of incentives to pursue basic science research may create a pipeline of new generalist faculty with a gap in basic science knowledge that belies its importance to their work. Our course was predicated on the idea that one way to combat this cycle is to offer faculty development.

Several publications have described programs to promote basic science interest among physicians and trainees, and found similar results to our experience. Spencer et al. found that integrating basic science into clinical practice stimulated interest in the sciences among undergraduate medical students, and that students were better able to recognize the relevance of pathophysiology to patient care.[18] A similar course for internal medicine residents found that residents developed an appreciation for physiology and an interest teaching physiology in clinical practice.[10] In contrast to these and other programs, our focus was on faculty already in practice and consequently further separated from the basic science curriculum of medical school.

While we found improved interest and confidence teaching physiology, we are not sure how durable these findings are. Although a single experience of relatively short duration may seem unlikely to have a lasting impact, one of our goals in the course was to promote a way of thinking, rather than just provision of discrete facts; in this respect, it is possible that the durability of the impact could be greater than predicted from the brief nature of the exposure. Due to the geographic distribution of participants and small sample size, we were also limited in our ability to explore higher level outcomes such as impact on learners or integration of physiology teaching with clinical care.

The design of the course and unique location offer numerous advantages, but may be too resource intensive in cost and staffing for other programs to replicate. Ready access to a research lab for animal procurement and handling may also be a barrier to program scaling. While other strategies such as asynchronous physiology teaching and simulated experiments are likely cheaper and more readily accessible, we believe much would be lost by eliminating the hands-on experimentation and community building aspects inherent in this program.

We believe that generalists are uniquely positioned to incorporate physiology principles into clinical practice. The close monitoring of inpatients allows generalists to observe physiologic changes in real time. For example, witnessing a patient's cognition improve with rate control of supraventricular tachycardia, or watching the creatinine improve with diuresis in the setting of heart failure. The clinical laboratory of inpatient medicine allows for easy integration of teaching physiology in clinical practice. Moreover, incorporating mechanistic thinking and teaching physiology only serves to promote system-based practice efforts and improve patient safety, both of which are central to the ethos of a generalist. In fact, cognitive errors are considered the most common cause of diagnostic error[19] and most adverse events that result in malpractice suits are actually errors in thinking rather than knowledge.[20]

One potential strategy to promote interest among generalists to both learn and teach basic science is through immersive faculty development and to directly connect abstract concepts with clinical care. Through use of experiments and mechanistic thinking to solve clinical questions, we were able to demonstrate relevance of basic science to patient care and reinvigorate enthusiasm for pathophysiology among general medicine faculty. We believe our experience offers one approach to bridging the widening gap between basic science and general medicine.

Acknowledgements: *The authors are extremely grateful for to the work of Deborah DeWaay, MD, and Stephanie Call, MD, in helping launching the first course in 2015. The authors would also like to express their deep gratitude for the numerous faculty who tirelessly volunteer their time to make this course possible every year, including Tony Breu, MD; Rich Schwartzstein, MD; Mark Tuttle, MD; Jeff William, MD; Melanie Hoenig, MD; Eric Osborn, MD PhD; Rick Solomon, MD; Rushad Patell, MD; Warren Hill, PhD; Bryce MacIver, PhD; Patricio Silva, MD; and Kate Spokes, BA, and the MDIBL staff including Jane Disney, PhD, and Chris Smith.*

Corresponding Author: *Daniel N. Ricotta, MD FHM; Department of Medicine, Beth Israel Deaconess Medical Center, Shapiro Institute for Education and Research, Boston, MA 02215, USA (e-mail: dricotta@bidmc.harvard.edu).*

Declarations:

Ethical Approval: *Ethical approval has been granted by the MDI Biological Laboratory IACUC board: protocol number c18-02.*

Conflict of Interest: *Drs. Ricotta, Hale, Freed, Zeidel, Scribner, and Herzig all receive nominal honorariums from the Mount Desert Island Biological Laboratory (MDIBL) for teaching in the Physiology on the Fly faculty development course.*
The Mount Desert Island Biological Laboratory is an independent, nonprofit biomedical research laboratory and all course proceeds are applied to course operating expenses and participants' room and board. None of the authors have any financial affiliation with MDIBL. None of the authors' affiliated institutions receive any financial benefit from the course.
Dr. Herzig reports grants from the Agency for Healthcare Research and Quality, outside of the submitted work.

REFERENCES

1. Natarajan P, Ranji SR, Auerbach AD, Hauer KE. Effect of hospitalist attending physicians on trainee educational experiences: A systematic review. *J Hosp Med.* 2009;4(8):490-498. doi:https://doi.org/10.1002/jhm.537
2. Woods NN, Neville AJ, Levinson AJ, Howey EHA, Oczkowski WJ, Norman GR. The value of basic science in clinical diagnosis. *Acad Med.* 2006;81(10 SUPPL). doi:https://doi.org/10.1097/00001888-200610001-00031
3. Woods NN, Brooks LR, Norman GR. The value of basic science in clinical diagnosis: Creating coherence among signs and symptoms. *Med Educ.* 2005;39(1):107-112. doi:https://doi.org/10.1111/j.1365-2929.2004.02036.x
4. DeFranco DB, Sowa G. The importance of basic science and research training for the next generation of physicians and physician scientists. *Mol Endocrinol.* 2014;28(12):1919-1921. doi:https://doi.org/10.1210/me.2014-1343
5. Seaburg LA, Wang AT, West CP, et al. Associations between resident physicians' publications and clinical performance during residency training. *BMC Med Educ.* Published online 2016. doi:https://doi.org/10.1186/s12909-016-0543-2
6. Mylopoulos M, Woods N. Preparing medical students for future learning using basic science instruction. *Med Educ.* 2014;48(7):667-673. doi:https://doi.org/10.1111/medu.12426
7. Chopra V, Burden M, Jones CD, et al. State of research in adult hospital medicine: Results of a national survey. *J Hosp Med.* Published online 2019. doi:https://doi.org/10.12788/jhm.3136
8. Shannon EM, Chopra V, Greysen SR, et al. Dearth of Hospitalist Investigators in Academic Medicine: A Call to Action. *J Hosp Med.*

2021;(Issue 2021-Feb ONLINE 1st):E1-E3. doi:https://doi.org/10.12788/jhm.3536
9. Do AND, Munchhof AM, Terry C, Emmett T, Kara A. Research and publication trends in hospital medicine. *J Hosp Med*. Published online 2014. doi:https://doi.org/10.1002/jhm.2148
10. Herzig SJ, Aird WC, Shah BJ, McKernan M, Zeidel ML. From hagfish to humans: Teaching comparative physiology to internal medicine residents. *Acad Med*. 2012;87(3):372-377. doi:https://doi.org/10.1097/ACM.0b013e3182444c1b
11. Breu AC. Why is a cow? Curiosity, tweetorials, and the return to why. *N Engl J Med*. 2019;381(12):1097-1098. doi:https://doi.org/10.1056/NEJMp1906790
12. Gonzalo JD, Haidet P, Papp KK, et al. Educating for the 21st-Century Health Care System. *Acad Med*. 2017;92(1):35-39. doi:https://doi.org/10.1097/ACM.0000000000000951
13. Brauer DG, Ferguson KJ. Medical Teacher The integrated curriculum in medical education: AMEE Guide No. 96 The integrated curriculum in medical education: AMEE Guide No. 96. Published online 2014. doi:https://doi.org/10.3109/0142159X.2014.970998
14. Krisberg K. Reshaping Medical Education with Innovative, Early Clinical Experiences. AAMC News.
15. Straus SE, Straus C, Tzanetos K. Career choice in academic medicine: Systematic review. *J Gen Intern Med*. 2006;21(12):1222-1229. doi:https://doi.org/10.1111/j.1525-1497.2006.00599.x
16. Evans DH. *Marine Physiology down East: The Story of the Mt. Desert Island Biological Laboratory*. 1st ed. Springer; 2015. doi:https://doi.org/10.1007/978-1-4939-2960-3
17. Allen-Dicker J, Hall AM, Donahue C, et al. Top qualifications hospitalist leaders seek in candidates: Results from a national survey. *J Hosp Med*. 2019;14(12):754-757. doi:https://doi.org/10.12788/jhm.3241
18. Spencer AL, Brosenitsch T, Levine AS, Kanter SL. Back to the basic sciences: An innovative approach to teaching senior medical students how best to integrate basic science and clinical medicine. *Acad Med*. 2008;83(7):662-669. doi:https://doi.org/10.1097/ACM.0b013e318178356b
19. Graber ML, Franklin N, Gordon R. Diagnostic error in internal medicine. *Arch Intern Med*. 2005;165(13). doi:https://doi.org/10.1001/archinte.165.13.1493
20. CRICO Strategies. *2014 Annual Benchmarking Report: Malpractice Risks in the Diagnostic Process*.; 2015.