Respiratory Medicine
Series Editors: Sharon I.S. Rounds · Anne Dixon · Lynn M. Schnapp

Patricia A. Kritek
Jeremy B. Richards *Editors*

Medical Education in Pulmonary, Critical Care, and Sleep Medicine

Advanced Concepts and Strategies

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Preface

Medical education is changing. The way we teach students, residents, fellows, and faculty has evolved over the past decade, and teaching practices that endured for centuries are being replaced or retired. This evolution is informed by advances in cognitive psychology and by evidence from a growing body of medical education research. Awareness of how medical education theory and practice is changing is critical for pulmonary and critical care specialists to understand how to best teach our learners in the classroom, in the clinic, on the consult service, and in the intensive care unit.

There is now greater emphasis on learner engagement and involvement in teaching and learning. Rather than educational sessions being defined by an instructor *teaching* learners, the emphasis of educational sessions should be on working through problems collaboratively with learners actively engaged in answering questions and solving problems. Active application of knowledge serves to solidify core concepts and reinforce real conceptual and practical understanding.

This modern, effective, and evidence-based approach to teaching and learning is particularly relevant to pulmonary and critical care medicine. The mechanistic and dynamic basis of pulmonary physiology, pathophysiology, and clinical practice lends itself well to active application (as opposed to rote memorization and regurgitation). As emphasized throughout this text, regardless of the setting or the learner, pulmonary and critical care topics can be more effectively taught through active teaching strategies. Just as importantly, using active teaching strategies can increase the enjoyment and satisfaction of teaching for pulmonary and critical care educators! Shifting the focus of teaching sessions from trying to transmit information from the instructor to learner to prioritizing discussion, interaction, and problem-solving can be invigorating for both learners *and* faculty.

A prime example of shifting the focus of teaching sessions and increasing enjoyment for learners and faculty is the standard didactic lecture. An individual talking to a large audience in an effort to transfer information in a unidirectional manner has been consistently shown to be ineffective. Some studies have demonstrated that audience members remember as little as 10% of the content delivered in a standard lecture. As such, the traditional didactic lecture is an increasingly anachronistic teaching modality, as active teaching strategies are supplanting the "sage on a stage." Specifically, as described in the chapters "Teaching in the Classroom: Large Groups" and "Teaching Preclinical Students," educators have experimented with different teaching techniques in the large group setting. And, through medical education research studies, several of these techniques have demonstrated improved engagement of learners in the large group setting, improved retention of knowledge, and improved performance on quizzes and tests. From peer instruction to case-based collaborative learning, these novel and active teaching techniques are more effective than standard lectures, and they are changing how we teach our learners.

A pulmonologist who is preparing a "lecture" needs to know about changes in best practices in large group teaching in order to develop a session than is as effective as possible. A lecture founded entirely on reading through PowerPoint slides with minimal opportunity for interaction is both an outdated approach to teaching and a missed opportunity. Embracing the concepts of the flipped classroom and active teaching maximizes the chances of the audience effectively engaging with and retaining the material. As one example, the pulmonologist could use an audience response system to strategically encourage audience members to *apply* their knowledge and understanding of a topic to solving a relevant problem.

Changes in medical education are also occurring outside of the classroom. Historical approaches to teaching in clinical environments are evolving, and strategies for leveraging learners' autonomy, engagement, and application of knowledge result in more effective understanding and growth. As described in the chapters "Teaching in the ICU," "Teaching in the Clinic," and "Teaching on the Wards," active teaching strategies are both important and effective tools for these settings. An appreciation of the impact of system-based, environmental, and logistical considerations on the effectiveness of teaching in these different environments is essential. Specific examples of active teaching strategies discussed in these chapters range from the well-described "One-Minute Preceptor" model and the SNAPPS format for use in the ambulatory setting to the CARE (*c*limate, *a*ttention, *r*easoning, *e*valuation) model in the ICU or on the wards. These different strategies are evidence-based means of optimizing learner engagement and knowledge application. Furthermore, these approaches foster self-directed and lifelong learning skills which are critical for long-term success in training and clinical practice.

In the twenty-first century, not all teaching and learning occurs in a physical location – the ubiquity of the Internet and web-based education is part of our contemporary medical and educational practice. Despite this reality, resources guiding medical educators on how to use the Internet, social media, and other web-based tools are scattered, difficult to find, and sometimes contradictory. In the chapter "Web-Based Learning," approaches to effectively harnessing these powerful tools for in- and out-of-classroom teaching and learning are discussed. Specific themes covered in this chapter include strategies for assessing the accuracy of web-based content for teaching purposes, the role and utilization of learning management systems, blending in-person and online teaching, and best practices for using social media platforms for medical education.

In addition to considering active teaching strategies for different physical and virtual settings in pulmonary and critical care medicine, approaches to teaching learners of different levels are highlighted in this textbook. Strategies that may be effective for medical students in the classroom setting (see the chapter "Teaching Preclinical Medical Students") may not be appropriate or effective for teaching fellows (as reviewed in the chapter "Teaching Fellows"). PCCM educators and faculty also interact with resident physicians in a variety of educational and clinical venues including the ICU, pulmonary consult service, and the outpatient clinic setting. Strategies to consider for working with and teaching residents in pulmonary and critical care clinical settings are reviewed in the chapter "Teaching Residents." Finally, medical students in the clinical or clerkship setting are an important group of learners with unique educational and development needs. The strategies for incorporating students into clinical practice in a meaningful and appropriate manner are discussed in the chapter "Teaching clinical medical students." Blending the importance of allowing autonomous clinical reasoning and supporting professional development is key for clinical medical students, as passive observation (or "shadowing") is analogous to being a passive audience member in a lecture – the effectiveness, value, and retention of lessons learned in the moment are diluted and less likely to be sustained when compared to active, autonomous clinical teaching experiences.

The role of simulation for learners of all levels is reviewed in the chapter "Teaching with Simulation." Simulation is an unquestionably important educational tool as learners can practice active application and problem-solving in a low-stakes environment without risk of patient harm or adverse events. Understanding best practices in simulation is critical, however, as poorly designed or ineffectively organized simulation scenarios can have limited educational value for learners or even be counterproductive to the educator's intent.

Communication skills are essential to effective clinical practice, yet teaching communication skills is not consistently explicitly emphasized in medical education curricula. Considering how to effectively teach communication and teamwork skills to learners of different levels in pulmonary and critical care settings is explored in the chapter "Teaching Communication Skills." The importance of interprofessional education and clinical practice, the necessity of clear and understandable communication with patients and families, and the need for cogent and understandable documentation are incorporated into the discussion of best practices for teaching communication skills. From the pulmonary clinic to the intensive care unit, communications skills are a foundational and necessary component of training and practice in pulmonary and critical care medicine.

Finally, while feedback is considered to be a critical component of medical education and clinical training, it is frequently perceived as a challenge for both learners and faculty. In the chapter "Role of Feedback in Teaching," different definitions of feedback (formative versus summative, brief versus formal versus major) are reviewed, and best practices in preparing and delivering feedback are delineated.

Throughout this textbook, we emphasize that changes to medical education are a good thing. Active learning is evidence-based and yields better understanding and retention. Active learning lends itself well to pulmonary and critical care medicine, as emphasizing mechanisms and highlighting conceptual connections forms a foundation for understanding core principles in our field. And, active learning is more satisfying, enjoyable, and fun than passive, unidirectional, and hierarchical teaching methods. We hope that this textbook provides you with the perspective and teaching tools to engage in effective and enjoyable teaching of your learners in pulmonary and critical care medicine.

Seattle, WA, USA — Patricia A. Kritek
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Chapter 1
Teaching Pre-clinical Medical Students

Jeremy B. Richards and Richard M. Schwartzstein

1.1 Introduction

The classic paradigm for the undergraduate education of medical students is for students to spend a significant quantity of time in the classroom setting [1]. Historically, medical students would spend 2 years engaged in primarily classroom-based learning focused on the foundational science needed to diagnose and treat patients, followed by an intensive year of clinical learning in a series of clerkship rotations. Classroom-based learning was termed the "pre-clinical" or "pre-clerkship" component of medical school, while the clerkship rotations were defined as the "clinical" component.

Models of undergraduate medical education are changing, however, and the pure distinction between pre-clinical, classroom-based learning and clinical, clerkship-based learning is evolving [2, 3]. Contemporary approaches to undergraduate medical education (UME) include shortened pre-clinical experiences and/or blended classroom and clinical experiences. Some medical schools prioritize patient contact and clinical learning very early in the UME curriculum, while other medical schools incorporate longitudinal patient care experiences into classroom-based formats; the rationale for the early clinical contact is partly to provide a context for the learning of basic sciences, to increase the motivation of students by quickly offering relevance for the material they are studying, and to assist in professional identity formation [4]. It is worth noting that the intensive clinical clerkship experience remains a core component of most UME curricula in the United States, although the timing of the clerkships can vary between medical schools (some schools schedule the core

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clerkships during the 2nd year of medical school, some during the 3rd year) and experiments with various forms of longitudinal clinical experiences continue [4, 5].

The result of these innovations in UME curricula is that a universal model of medical student education no longer exists. Despite the increased emphasis on early clinical experiences in UME, the classroom remains an important venue for teaching core concepts, as well as nurturing problem-solving abilities and critical thinking skills with medical students. Furthermore, with increasing use of new interactive techniques and strategies, classroom teaching can be fun and inspiring for the student. To use this venue to meaningfully teach students and promote personal growth and career development remains an enormous opportunity and responsibility of pre-clinical educators, including pulmonary and critical care physicians.

In this context, the classroom should be seen not as a constrained space to pound facts into the heads of unsuspecting young adults but as a laboratory to explore the mysteries of the human body and to create hypotheses, using physiological and molecular concepts, to explain health and disease. Consequently, the emphasis can be on an *approach* to learning, the development of problem-solving skills and critical thinking abilities in the pre-clinical setting, which will set the stage for future learning and thinking when students enter the clinical setting. Done correctly, teaching in the pre-clinical setting may impact how students think and function over their entire careers, as students can be provided the knowledge, skills, and attitudes to address novel problems encountered in clinical practice.

With this perspective, this chapter will review specific strategies for teaching students in the pre-clinical setting, with a focus on knowledge, skills, and behaviors relevant to pulmonary and critical care medicine (PCCM). Concepts of critical thinking and cognitive psychology relevant to pre-clinical medical students are discussed, and best practices in classroom-based teaching are elaborated. Teaching in the pre-clinical setting is an opportunity to positively influence future physicians in a meaningful and valuable manner, and employing effective and evidence-based strategies to achieve this goal will maximize educators' chances of success.

1.2 Teaching Pre-clinical Students How to Think

1.2.1 Theory and Practice: Cognitive Psychology and Critical Thinking

In addition to practical considerations about how to teach and assess critical thinking skills in pre-clinical learners, understanding relevant cognitive psychologic theory is important when developing educational interventions and curricula for UME learners. Specifically, awareness of the role of working memory and cognitive load theory, the concepts of dissonance and interference, and the effects of heuristics and cognitive biases are all important foundational cognitive psychologic principles in teaching at any level, including when teaching pre-clinical students.

Working memory describes the concept in which a person has a limited cognitive capacity to truly consider and assess new information [6]. Working memory can be alternatively referred to as focus, bandwidth, or capacity to incorporate novel stimuli, knowledge, or concepts. Random access memory (or RAM) on a computer's hard drive is a rough analogy for working memory. There is no effective manner to accurately predict or quantify an individual student's working memory, but being aware of the risk of cognitive overload is a first and necessary step to avoiding overwhelming a learner's working memory [7]. One strategy to avoid overwhelming working memory is to dedicate time for learners' to grapple with new knowledge or concepts with the goal of truly internalizing this new information. In class discussions, problem-solving exercises and spaced education (e.g., returning to challenging concept iteratively over the course of a session or a curriculum) are strategies for acknowledging the concepts of working memory and cognitive load.

A specific example of acknowledging the concept of working memory would be for an instructor to pause during his lecture about LaPlace's law, encourage students to engage in an interactive classroom discussion about factors that influence alveolar surface tension. To allow for students' working memories to process these concepts, the instructor should ensure students have ample time to discuss the relevant physiologic concepts with each other and then *explain* their understanding of how different parameters affect alveolar surface tension to their classmates.

Dissonance is the cognitive psychological concept in which a person realizes that his or her understanding of a topic or concept is incorrect or incomplete [8]. The sense of discordance that accompanies such a revelation can be a very important motivator to apply cognitive effort to understanding a new concept or topic, and dissonance can be effectively used to stimulate independent, self-directed, and lifelong learning [9]. Of course, this may not feel "good" to the learner; this is effortful learning, which is more likely to lead to enduring knowledge, but human nature may put up resistance to doing the work. Determining what a student believes he or she understands about a topic or concept is a first step toward leveraging dissonance, and coupling dissonance with the concept of working memory and cognitive load is important to allow learners to address cognitive discord and dissonance [9].

A specific example of employing dissonance in teaching would be to challenge students' to explain the mechanism by which a pulmonary embolism (PE) causes hypoxemia. Working through the pathophysiology of pulmonary embolism will result in students realizing that a PE obstructing a pulmonary artery should increase dead space, resulting in hypoventilation but not necessarily hypoxemia. The dissonance invoked in students by this revelation can increase their motivation to and retention of how a PE *actually* causes hypoxemia.

Interference describes the role of internal and external distractors to engaging in cognitively effortful activities including learning and internalizing new concepts [10]. Internal interference can include processes such as competing obligations, personal or emotional distractors, and lack of motivation to learn. External interference can include environmental phenomenon (e.g., the physical learning environment), cognitive overload, and limited working memory. Educators should be aware of the potential impact of interference on students' abilities to engage in cognitively effortful activities, and educators should endeavor to address interference when possible to maximize students' chances of meaningfully engaging with and incorporating concepts into their working memory [11].

Cognitive psychologic theory describes two "modes" of thinking, referred to as System 1 and System 2 thinking [12–16]. System 1 thinking is a reflexive, pattern recognition mode of thinking in which information is rapidly processed and conclusions are made almost automatically [12, 13]. An example of System 1 thinking is when a patient who has smoked for 20 years states that she has heard herself wheezing and the physician immediately assumes the patient has COPD. The automatic, reflexive association between tobacco exposure, wheezing, and COPD comes easily and without much cognitive effort [16].

System 2 thinking is a more cognitively effortful, analytic mode of thinking [12, 13]. In the example of the wheezing patient, System 2 thinking would entail comprehensively reviewing all of the patient's symptoms, past medical history, laboratory, and imaging data and concluding that the patient's wheezing is due to chronic diastolic congestive heart failure resulting in increased airway edema. Teaching critical thinking skills in the classroom can prepare students to take data (history, physical exam findings, laboratory results) and work comprehensively, using a System 2 approach, and inductively create a solution to a clinical problem.

Heuristics are mental shortcuts used reflexively and intuitively in daily life as well as in clinical reasoning and problem-solving [17]. Heuristics include cognitive biases, which are a series of cognitive shortcuts or generalizations used to simplify problem-solving activities and decrease the cognitive effort required to reach a conclusion or solution. Cognitive biases include processes such as anchoring, availability bias, and base rate neglect (see Table 1.1) and are commonly used in daily and clinical settings

Table 1.1 Types of cognitive bias

Cognitive bias	Definition
Anchoring bias	Tendency to lock onto specific features in a patient's presentation too early in the diagnostic process and a failure to adjust the initial impression in response to new information
Availability bias	The propensity to judge diagnoses as being more (or less) likely to occur if those diagnoses more readily come to mind (or do not readily come to mind)
Base rate neglect	Tendency to ignore the true prevalence of a condition or disease by either exaggerating or diminishing the base rate of the disease
Diagnostic momentum	The propensity to carry forward a diagnostic label once it is applied to a patient's condition
Gambler's fallacy	The belief that if a coin is tossed ten times and lands on heads each time, the 11th toss has a greater than 50/50 chance of landing on tails
Outcome bias	The tendency to focus on diagnostic possibilities that increase the likelihood of a good outcome for a patient
Sunk costs bias	The more one invests in a given diagnosis as the explanation for a patient's symptoms, the less likely one is to be able to consider alternative possibilities

to reach rapid and common answers to problems [18, 19]. Cognitive biases and heuristics are founded on System 1, pattern recognition reasoning [12, 13].

Understanding the ubiquity of heuristics and cognitive biases in human reasoning is necessary to allow medical educators to effectively address these mental shortcuts in students' approaches to solving clinical and conceptual problems. Strategies for addressing heuristics and cognitive biases primarily involve education, recognition, and prioritization of analytic reasoning strategies. Awareness and transparency about the presence and ubiquity of these cognitive shortcuts is a critical first step in teaching students how to understand and address them.

1.2.2 Critical Thinking in the Classroom

Medical education, particularly classroom-based, pre-clinical education, is commonly compared to "trying to drink from a firehose" [3]. The quantity of medical knowledge is enormous and continuously growing, and to expect students to master the breadth and depth of contemporary medical knowledge is simply unrealistic. With our present technology, finding facts is easy; every student carries a computer in her pocket. Of course, one can't constantly look up every fact one needs to know as a doctor, but we can de-emphasize the rote memorization that once characterized the process of becoming a physician. Furthermore, medical educators who attempt to simply transmit knowledge to students are missing an opportunity to help students understand how to manage, interpret, and use information in an effective and efficient manner. Said differently, the focus of UME should not be on transferring information from educators to students; rather, teaching students how to critically appraise, synthesize, and use medical knowledge is a markedly more important goal for contemporary medical educators [2–4]. Bloom's taxonomy, as described elsewhere in the text, is a useful framework that medical educators can use to assess students' knowledge, understanding, and ability to apply information to solving problems and answering questions [20].

While academic and popular sources commonly refer to critical thinking skills, there is not a universally agreed upon definition of critical thinking. Various authors and experts have offered conceptual and practical definitions of critical thinking and critical thinking skills (see Table 1.2). A shared theme from these various definitions is the ability to synthesize and analyze information and apply the conclusions of synthesis and analysis to addressing a problem. Working with these core elements of critical thinking, medical educators may develop educational interventions and teaching strategies to prioritize synthesis, analysis, and application, as opposed to prioritizing transfer of information, memorization, and pattern recognition. These principles can be applied to teaching pulmonary and critical care content in the classroom setting, as students can develop critical thinking skills by asking questions about and solving problems regarding respiratory physiology or pathophysiology.

Best practices in clinical reasoning emphasize the importance of engaging in inductive reasoning to develop diagnostic hypotheses, as opposed to using a

Table 1.2 Definitions of critical thinking

Authors/groups	Definition
Croskerry [21]	Advanced (stage 6) critical thinking: Accomplished level of critical thinking – has systematically taken charge of their own thinking and continuously strives for improvement and to develop new insights into deeper levels of thought
Bacon [22]	Critical thinking is a desire to seek, patience to doubt, fondness to meditate, slowness to assert, readiness to consider, carefulness to dispose and set in order, and hatred for every kind of imposture
Millennium Conference [23]	Applying higher cognitive skills (e.g., conceptualization, analysis, evaluation) to information either gathered from medical history or records or generated by physical exam or laboratory investigation, in a way that leads to action that is precise, consistent, logical and appropriate
American Psychologic Society [24]	Purposeful, reflective judgment which manifests itself in reasoned consideration of evidence, context, methods, standards, and conceptualizations in deciding what to believe or what to do

hypothetico-deductive reasoning approach to clinical reasoning [25, 26]. Inductive reasoning is described as comprehensively reviewing all available data to develop a series of hypotheses, typically framed in terms of anatomy and pathophysiology rather than diagnoses that best fit the available information [25]. Comparatively, a hypothetico-deductive approach to clinical reasoning involves first identifying a discrete set of diagnostic hypotheses based on a limited set of data and then determining if the remaining clinical information fits those pre-specified hypotheses [26].

The risk of hypothetico-deductive reasoning is that diagnostic possibilities are missed due to a limited differential diagnosis based on the initial pattern or erroneous conclusions influenced by cognitive biases early in the diagnostic process. Assuming a patient who is wheezing has COPD is an example of hypothetico-deductive reasoning. Reciprocally, inductive reasoning is generally considered to be more cognitively demanding, as it is an analytic, comprehensive approach to reviewing all available clinical data before forming diagnostic hypotheses; it takes greater mental effort relative to intuitive pattern recognition.

The brain is built to recognize patterns. Doctors absorb illness scripts, which are short summaries of the common features of different disease states, as they gain clinical experience [27, 28]. One can easily categorize and teach illness scripts, which are then memorized by students [28]. But when discordant data appear, the learner is prone to dismiss the information and commit a cognitive error [12]. By emphasizing inductive approaches early in medical education in the context of critical thinking, students have the tools to reason through confounding pictures and gain confidence that they can solve problems on their own. Teaching critical thinking skills in the classroom setting can prepare students to adopt an inductive approach to reasoning in the clinical setting.

There are no universally agreed upon approaches to teaching critical thinking skills in the classroom setting, but using active learning strategies will prioritize application of knowledge as compared to rote memorization and regurgitation of facts [29]. In this context, increasing emphasis on discussion, active participation, small-in-large groups (e.g., think-pair-share strategies), and audience response systems are increasingly employed in classroom-based UME settings. Of course, simply *using* these education interventions is insufficient to truly promote critical thinking skills, and thoughtful development of content and activities intended to promote analytic reasoning is necessary to prompt students to cognitively engage with material in a meaningful manner [30, 31].

1.2.3 Assessing Critical Thinking Skills

Similar to the lack of universally agreed upon strategies for teaching critical thinking skills, there is no consensus on the best means for accurately and reliably assessing critical thinking skills [23]. In general, conventional perceptions among medical educators indicate that closed-ended test questions (e.g., multiple choice questions) are less effective in accurately determining students' critical thinking abilities; cognitively, it is much simpler to recognize a correct answer than to generate an answer [32]. Open-ended questions and short answer or essay responses may provide more insight into students' ability to synthesize, analyze, and apply knowledge to solving a problem; however, the effort in grading open-ended questions is obviously much more significant than grading close-ended multiple choice questions [32]. Other potential means of assessing critical thinking skills include having students develop concept maps or mechanism maps [33], assessing students' performance in simulation scenarios [34–36] and oral examinations [37]; however, rigorous evidence for the accuracy, reliability, and predictive characteristics of these assessments is lacking.

Vignette: Teaching Critical Thinking Skills

You are invited to develop a teaching session about emphysema for first-year medical students in a core physiology course in the first semester of medical school. The students have had minimal patient contact at this point of their UME curriculum, but the physiology course does emphasize clinical application of physiologic concepts. You are interested in prioritizing clinical reasoning skills in your teaching session, and you develop a clinical vignette to serve as the basis for your session.

Your vignette features a 52-year-old man with a history of significant tobacco use who presents with several weeks of progressive dyspnea on exertion, audible wheezing, and a nonproductive cough. You develop questions intended to promote the application of knowledge to understanding and solving clinical problems:

1. Why is this patient wheezing? Describe specific pathophysiologic mechanisms to explain your answer.
2. How would administration of a beta-agonist affect his wheezing?
3. Why is this patient experiencing dyspnea on exertion? What findings would you expect to finding on spirometry to support your answer?

You are interested in teaching the students about the role of non-positive pressure ventilation (NIPPV) as a treatment for chronic obstructive pulmonary disease; however, you realize that for the time allotted for the session, trying to introduce the concept of NIPPV and to allow them time to truly consider and incorporate this concept would be a threat to their working memory and likely precipitate cognitive overload. As such, you do not try to include NIPPV into this session and instead focus on the learning objectives of applying physiologic principles to clinical manifestations and management of emphysema.

Take-home points: This vignette demonstrates the importance of appreciating and addressing *cognitive interference* in developing and implementing teaching sessions, the importance of asking "why" and "how" questions to stimulate higher-level System 2 reasoning, and the importance of developing an interactive session that is not simply a didactic lecture.

1.3 Strategies and Techniques for Applying Principles of Teaching that Emphasize Thinking Skills in Different Settings

A common mental image of pre-clinical teaching is of single instructor on a stage, lecturing to a large amphitheater filled with students [1–3]. While large group teaching settings remain a common and important component of pre-clinical teaching, there are numerous other settings in which pre-clinical students learn the content, concepts, and application of medicine. Small group teaching, medium-sized cohorts, and learning in the context of patient care are important settings in which pre-clinical teaching occurs, and specific considerations for providing optimized teaching in these settings are discussed below. Simulation-based learning, extracurricular activities, and learning in the context of research activities are other important educational opportunities for pre-clinical students but are beyond the scope of this chapter.

1.3.1 Large Group Teaching

The reflexive image of large group teaching is of a classic lecture hall with an instructor unidirectionally speaking to students who passively receive the information. This picture is increasingly anachronistic and this teaching strategy is most likely ineffective. Some researchers have found that students recall as little as 10% of lecture content 3 days after the lecture [38]. The literature provides numerous examples of the benefits of active learning in the large group setting, and incorporating evidence-based practices for large group teaching is critical to optimize students' chances of meaningfully and effectively learning relevant material and concepts.

Table 1.3 Active teaching strategies for use in large group teaching settings

Active learning strategy for use in lectures	Description
Peer instruction [39]	Break lecture material into short segments interspersed with conceptual questions which learners answer first on their own, followed by discussion with 3–4 colleagues to develop a group consensus answer
ACTIVE teaching format [40]	*Assemble* learners into small groups, *convey* 3–5 learning points, *teach* a limited amount of content, *inquire* about how the content applies to patient management, *explain* answer choices
Buzz groups [41]	Divide a large group of learners into pairs or small groups at the beginning of a lecture, which then collaboratively answer questions posed throughout
Audience response systems [42]	Assess individuals' responses to questions in real time using technologic ("clickers" or web-based platforms) or manual responses (paper-based or show of fingers)
Assign in-class writing [43]	During or after a lecture, learners write a brief summary of what they learned during the lecture
Think-pair-share [44]	Divide learners into pairs, and ask them to *think* about questions posed during the lecture, discuss the questions in *pairs*, and then *share* their consensus answer with the group

There are many different approaches to the incorporation of active learning into the large group setting (see Table 1.3). Some of these strategies can be categorized as "flipped classroom" activities [45]. The concept of a flipped classroom involves having students engage in study and pre-work prior to coming to class, such that the time in class can be dedicated to application of knowledge to solve problems as opposed to spending class time exclusively on being exposed to and starting to learn new knowledge. The term "flipped classroom" is sometimes used as if referring to a specific educational intervention, but it is more appropriately considered as an umbrella term or overarching category for a philosophy of teaching. Employing a flipped classroom approach to teaching indicates that the instructor is prioritizing class time for engagement and application as opposed to simple knowledge transfer. "Active teaching" strategies can be used in either a flipped classroom or more traditional classroom setting and describe specific educational interventions intended to allow students to apply knowledge to answer questions or work through problems.

The active teaching strategies described below are particularly effective for pulmonary and critical care topics. For example, the pathophysiology of asthma can be discussed and described in an iterative, interactive manner that involves students and emphasizes application of concepts. Similarly, the concepts of respiratory system compliance, with differential effects of the pulmonary parenchyma and the chest wall, can be the foundation for a problem-based, active learning session. The topics of pulmonary mechanics, physiologic and pathophysiologic mechanisms, and conceptual topics lend themselves well to active teaching and learning.

Specific flipped classroom and active teaching strategies to teaching in the large group include peer instruction, the use of audience response systems, think-pair-share, team-based learning, concept maps, and case-based collaborative learning.

1.3.1.1 Peer Instruction

Peer instruction is an active learning strategy that was first described by Eric Mazur and colleagues in a large undergraduate physics class [39]. Peer instruction requires students to complete independent pre-work prior to the large group teaching session, including completing a set of pre-class "readiness assessment questions" to gauge their understanding of the required pre-class material. Instructors have access to the class's performance on the readiness assessment questions prior to the large group teaching session, which can be helpful in identifying areas of particular difficulty for students [39, 46].

The large group teaching session comprises a series of short lectures, on the order of 7–10 minutes, intended to emphasize core concepts covered in the pre-class preparatory materials. After a short lecture, using an audience response system, students must answer a multiple choice question related to the concept discussed in the brief lecture. If less than 70% of the class answers the multiple choice question correctly, students are instructed to discuss their answer choice and their explanation for why they chose that answer with another student(s). The instructor observes the students' discussions to assess their understanding of the concept in question. After 2–3 minutes of discussion, the students again answer the same multiple choice question, and the instructor identifies the correct answer and addresses any misconceptions or faulty reasoning he or she perceived when observing the students discussing their answers. After completing this process, the instructor provides another short 7–10 minutes lecture on a core concept, and the process is repeated.

Peer instruction has been demonstrated to significantly improve students' conceptual understanding of foundational processes in physics [39, 47]. Mazur and colleagues studied students' performance on the Force Concept Inventory (FCI), a test widely used to assess conceptual understanding of physics. Students who were taught using peer instruction performed significantly better on the FCI than students who were taught using standard lecture-based pedagogy. While there are not robust empirical data regarding the impact of peer instruction in UME settings [46–49], it has been employed in classroom-based teaching in various institutions with adequate acceptability and feasibility parameters [50].

1.3.1.2 Audience Response Systems

Engaging learners through audience response systems is an increasingly common method used in large group teaching settings [42]. There are a variety of audience response systems for use, with varying functionality and cost associated with their use (see Table 1.4). Beyond the specific attributes and logistics of different audience response systems (ARS), however, the philosophy of active engagement and application of knowledge can be effectively leveraged by thoughtfully incorporating ARS into classroom-based teaching.

The key for effective use of ARS for pre-clinical learners is to develop questions that address conceptual understanding and that prioritize the application of critical thinking skills, and to have a concrete strategy for how one deals with students'

Table 1.4 Audience response systems

Audience response system	Comments	Website
Poll Everywhere	Poll Everywhere is free for use for up to 25 learners and primarily allows for use of multiple choice questions	www.polleverywhere.com
Turning point	Turning point is a proprietary system that embeds in PowerPoint and is not free for use	www.turningtechnologies.com
Kahoot!	Competition-based, user-friendly, mobile application for sending questions to participants	kahoot.com
Typeform	Survey delivery software that can be used for ARS questions	www.typeform.com

"voting" [51]. Simply asking students low-level, recall-based questions is missing the opportunity and promise of ARS. Furthermore, questions should be strategically incorporated into the content and structure of the teaching session; questions that are simply added into a teaching session will be minimally effective at best and distracting or counterproductive at worst [52]. If a question yields a range of responses, students can be asked to explain their reasoning, after which they can vote a second time or speak to the person next to them for a minute or two and then revote (see Sect. 1.3.1.3 below). Do not assume that because the majority of students responded correctly that they all understand the reason why the answer chosen is correct.

Best practices for using ARS for teaching pre-clinical learners are primarily founded on consensus opinion and educational theory [42]. Data describing quantitative outcomes attributable to ARS in the pre-clinical, classroom-based setting are of variable quality and difficult to broadly generalize to all UME teaching settings.

1.3.1.3 Think-Pair-Share

This educational intervention is a structured approach to promoting active engagement and discussion in a large group teaching setting. Think-pair-share is a methodology in which an instructor asks a conceptual question to the class and allows students time to think about and, ideally, write down their answers to the question [44]. Students then discuss their answer to the question, and their justification for their answer, with a partner. After having several minutes to discuss their answers and conceptual understanding, a series of "pairs" of students are asked to share their perspective on the questions with the overall class.

Think-pair-share is a powerful means of promoting application of knowledge, as students must not only commit to an answer, but they must defend and justify their answer – not only to their partner in the think-pair-share dyad but potentially to the entire class. The accountability intrinsic in the think-pair-share methodology and the emphasis on assessment, synthesis, and application of knowledge promote critical thinking skills and emphasize active learning [53].

Topics in pulmonary and critical care medicine lend themselves well to using the think-pair-share technique. For example, exploring the meaning of a high peak pressure with a low plateau pressure in a mechanically ventilated patient is a specific topic that can generate discussion and interaction using the think-pair-share method. The active discussion of knowledge application and problem-solving both engages and provides benefit to students.

1.3.1.4 Team-Based Learning

Originally described by Michaelsen, team-based learning (TBL) is a medium or large group teaching modality that incorporates a regimented approach to student preparation, assessment, and participation in teaching sessions [54]. TBL relies on pre-class preparation, as students are expected to have completed pre-class work and reading, such that they have a shared foundation of knowledge and understanding prior to in-class activities; consequently, it incorporates many of the elements of the flipped classroom approach [54, 55]. To assess the degree of students' pre-class preparation, at the beginning of the class session, students complete a readiness assessment exercise, referred to as an "individual readiness assessment test" (iRAT), which involves a discrete series of multiple choice questions intended to demonstrate students' understanding of core topics and concepts.

After completing the iRAT, students share their individual answers with a prespecified group of students (their "team") and discuss the rationale and justification for their answer selections. With their team, students are expected to reach a consensus about the "best" answer to the readiness assessment questions; the exercise of reaching group consensus is referred to as a "group readiness assessment test" (gRAT). Each group is expected to be ready to share their consensus answers from the gRAT component with the entire class, and discussion regarding different conclusions, misconceptions, and conceptual understanding can occur in a facilitated fashion. The conclusion of the large group discussion should end with the instructor clearly identifying the correct answers and assessing for shared understanding among all students.

The cycle of iRAT, gRAT, and group discussion typically occurs two to three times during a TBL session, and strict time management and conscientious faculty facilitation are critical to ensure that the TBL session does not fall victim to tangents or unproductive discussions.

1.3.1.5 Concept Maps

Concept maps or mechanism maps are visual representations of one's knowledge about and understanding of a topic or concept [33]. Concept maps are classically defined as a hierarchical flow diagram in which a primary topic or concept is defined based on its component or mechanistic parts (see Fig. 1.1). Mechanism maps are a variation of concept maps that are less explicitly hierarchical in nature and may be more appropriate for the complicated, interrelated nature of medical concepts (see

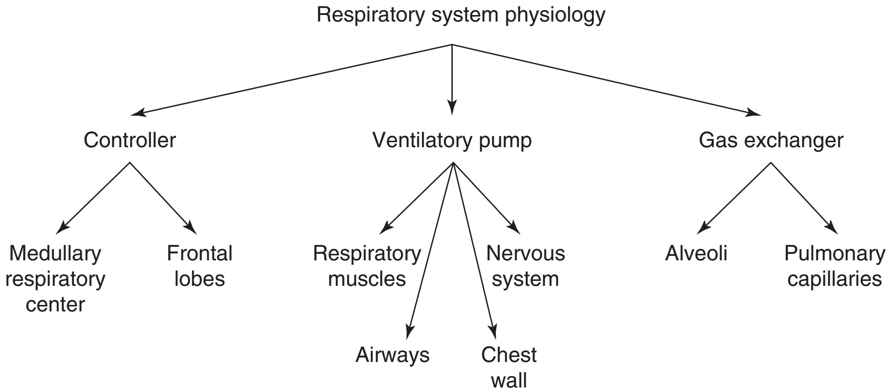

Fig. 1.1 Example of concept map

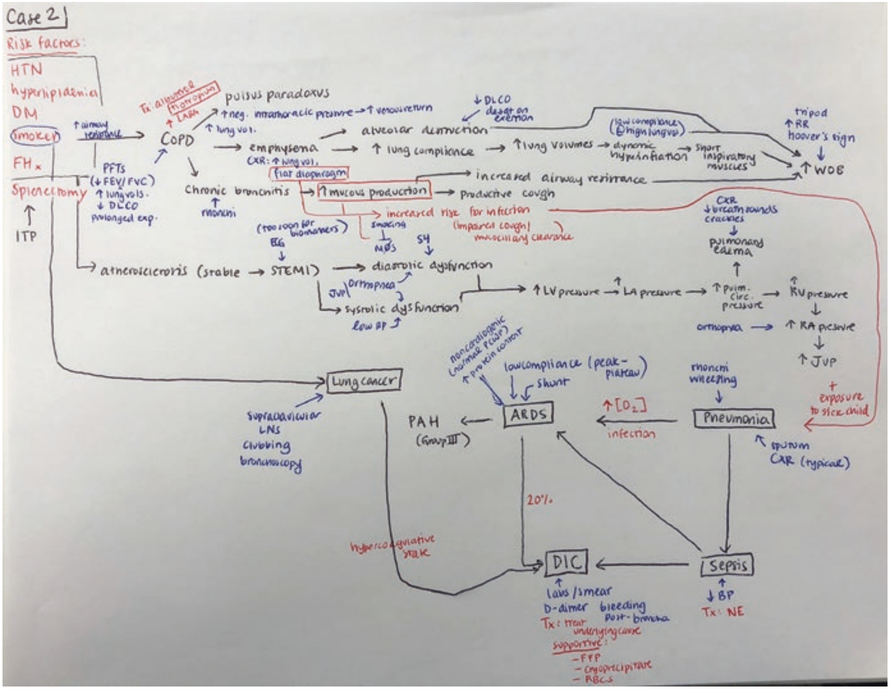

Fig. 1.2 Example of a mechanism map

Fig. 1.2). Mechanism maps are particularly effective in visually representing interconnected physiologic or pathophysiologic mechanisms and can be powerful tools to teach, study, and review linkages between concepts and mechanisms for pulmonary and/or critical care topics.

Concept and mechanism maps can be used in a variety of educational settings, from individual study to small group teaching to large group educational sessions [33]. In the large group setting, concept or mechanism maps can be created as a component of a lecture-based or interactive teaching session to graphically represent how different medical topics and concepts relate to each other. Developing concept or mechanism maps in real time in the large group teaching setting can both model critical thinking skills (by explicitly demonstrating how to assess and synthesize data) and can encourage students to develop their own concept or mechanism maps for individual, self-directed learning and conceptual integration [56].

1.3.1.6 Case-Based Collaborative Learning

Described in detail below in the *small group teaching* section, case-based collaborative learning (CBCL) is a flexible teaching modality that may be used in small, medium, or large group settings [57]. The principles and logistics of CBCL described below can be applied to larger groups of students.

1.3.1.7 Expectations of Students

Pre-class preparation is implicit in all of the abovementioned active teaching strategies for the large group setting, and clearly delineating the need for independent, pre-class reading and studying is important to maximize the utility of such teaching modalities. While there is no single ideal strategy to optimize students' pre-class preparation, contextualizing the importance of student preparation as a component of professional responsibility and professional development may be effective. Furthermore, instructors must be consistent with regard to accountability – if some students have not completed the necessary pre-class work and are unable to meaningfully participate in the active teaching session, the responsibility for that outcome rests with the students. Instructors should avoid reviewing pre-work during the teaching session, such that students who did not prepare can be brought up to speed, as doing so will demonstrate that students do not actually have to complete pre-work independently prior to the teaching session [45].

1.3.1.8 Challenges for Active Teaching in Large Group Settings

In addition to the challenge of students not preparing for large group active teaching sessions, there are other obstacles to effectively transitioning from didactic, lecture-based large group teaching to interactive, active teaching sessions.

Faculty resistance to change can be a significant barrier to curricular reform and to implementing novel, active teaching pedagogy in the classroom setting [58]. Faculty members may be suspicious of the utility of active teaching and may be concerned about the necessary reduction in content delivery that occurs with transitioning from lecturing to active teaching. In this context, faculty development is critical.

An emphasis on evidence-based outcomes associated with and attributable to active teaching modalities can be influential, and skills development sessions and resources for faculty are important to help instructors succeed in an active teaching format.

Transitioning from lecture-based classroom teaching to active teaching strategies is time-consuming [59]. One study documenting faculty effort when transitioning from a standard curriculum to a flipped classroom curriculum demonstrated that faculty time in preparing course materials increased by 127% [60]. Being cognizant of the time and effort needed to develop, implement, and assess active teaching modalities, particularly when transitioning from standard curricula, is important to optimize faculty buy-in and to minimize potential faculty resentment about using flipped classroom, active teaching strategies.

Other potential barriers to using active teaching strategies in the large group setting include technologic limitations and system-based issues. For example, while there are a number of ARS platforms available (see Table 1.4), if one's medical school does not have the technologic infrastructural or institutional experience with a given ARS, technical issues may arise during teaching sessions. Such technical issues can disrupt the flow and perceived value of a teaching session and can contribute to student and faculty disengagement or even resentment. Anticipating potential technical issues, test-running any ARS platform before a teaching session, and preparing non-technologic alternatives as a contingency plan are strategies to mitigate the distraction of computer or Internet failures during a teaching session.

System-based issues that can threaten implementation and sustainability of active teaching sessions include the challenge of inaccurate or inconsistent assessment methods of active teaching sessions. Students' perceptions of the utility of teaching sessions are consistently valued by medical school administrators, and while students' input is helpful, it has been demonstrated that while active teaching strategies consistently improve students' performance on exams, students may rate active teaching sessions less favorably than passive, didactic, lecture-based sessions [61–63]. This disconnection between the effectiveness of active teaching session and students' perceptions of the acceptability of these sessions is a challenge for instructors and administrators. Although the reasons underlying this observation are probably varied, interactive learning and generating solutions to problems are inherently more effortful for the learner than being told the right answer (recall the concepts of working memory, dissonance, and interference). Awareness of this disconnect is an important step in understanding students' evaluations, and identifying other metrics of effectiveness of teaching sessions beyond students' self-reported perceptions is important to accurately and reliably assess the value of these teaching sessions and teaching strategies.

Finally, a challenge of flipped classroom and active teaching strategies is that students are obligated to complete a significant quantity of out-of-class work. There is risk that students may feel overwhelmed by the workload, and rather than simply not completing pre-class work, they may not be able to keep up with the pre-class work [64]. Ensuring that pre-class materials are high quality, focused, and meaningful is important to maximize student engagement and decrease the risk of them not being able to complete pre-class assignments. Specifically, simply video recording lectures for students to watch is generally not effective pre-class work; rather, more focused and engaging resources are appropriate as preparatory materials. In addition, achieving a balance between pre-class and in-class work is important, as crucial learning objectives and key concepts can and should be reviewed in class to emphasize their importance and reinforce lessons learned by students from their pre-class studies.

Vignette: Active Teaching in the Large Group Setting

You have been giving a lecture about interpreting respiratory acid/base disorders as part of a first-year medical school physiology course for the past 3 years, and this year the course director informs you that the course will be adopting active teaching strategies for the large group teaching sessions. You are instructed to reformat your lecture from a didactic presentation to a more interactive active teaching session. After a faculty development session about active teaching strategies led by the course director for the course faculty, you decide to use peer instruction to reformat your respiratory acid/base disorder session.

You review the learning objectives for the session and reformat them to prioritize analysis, synthesis, and application of primary concepts from your lecture. You then divide the lecture into six subcomponents, and you develop brief 7–10 minutes “mini-lectures” for each subcomponent. You incorporate a conceptual multiple choice question from prior year’s quizzes and final exams to present after each mini-lecture. You practice your teaching session with a small cohort of faculty and revise the length and some content of your new active teaching, peer instruction session based on their feedback.

On the day of your teaching session with students in the physiology course, the ARS you chose to use to present the conceptual multiple choice questions isn’t working. You have the questions available as PowerPoint slides, however, and are able to display them to the class after your mini-lectures, although you are unable to determine the proportion of correct versus incorrect responses in real time.

After the session is over, you solicit feedback from students and co-faculty about what went well and what could be improved for next time. Beyond the issues with the ARS, several people comment that the “peer instruction” portion of the session, when students discussed their individual answers with colleagues, may have been too long. Otherwise, the feedback is generally positive, and you are satisfied with the transition from lecturing to actively teaching in the large group setting.

Take-home points: This vignette demonstrates the role of developing content, organizing material, practicing teaching before the session itself, and engaging in contingency planning when using active teaching strategies, particularly in the large group setting. Actively soliciting feedback is also an important consideration to ensure that opportunities to improve the teaching session are captured.

1.3.2 Small Group Teaching

Classically, discussion and interactive learning have occurred in small group teaching sessions in the pre-clinical, classroom-based component of medical school, and a variety of educational methodologies exist for approaching small group teaching.

1.3.2.1 Problem-Based Learning

Problem-based learning (PBL) is a student-centered approach to small group teaching and learning. The philosophy of PBL is to prioritize students' curiosity and inquisitiveness [65]. PBL small group sessions tend to be case-based learning experiences, founded on a clinical scenario or vignette, and the agenda for PBL sessions is primarily set by students as opposed to faculty. Students receive a clinical vignette in advance of the PBL session and have time to independently review the vignette to identify questions or areas of confusion. Conceptually framed as a "safe space" for students to engage in active exploration about topics, concepts, or components of the clinical vignette that are of interest to them, PBL sessions leverage student engagement and participation by allowing them autonomy in determining the direction and depth of discussion [66].

PBL sessions are typically composed of six to ten students with a faculty facilitator. The facilitator is intended to act as a "guide on the side," rather than a leader of the sessions. The primary role of PBL faculty is to identify misconceptions or errors in students' reasoning as students discuss aspects of the clinical vignette of interest to them. The facilitator is not intended to drive the agenda of the PBL session or the direction of discussion. Facilitators may also participate by drawing out quieter students, to ensure their voices are heard in the group discussion, but the faculty facilitator is not supposed to dominate the discussion [67].

Students in PBL sessions may identify a "leader" for each session, and the student "leader" may help to determine the agenda and discussion topics for a given session. The role of student leader should rotate, as a single student, or cohort of students should not be identified as leaders for a longitudinal series of PBL sessions. Sharing leadership responsibilities underscores the democratic and collaborative nature of PBL sessions, emphasizing teamwork skills and a sense of community and shared responsibility [68].

PBL has been extensively studied and has several strengths. First, PBL prioritizes students' interests and thereby can optimize student engagement and participation. Having students set the agenda for their sessions hopefully translates to students who are invested in participating in their discussions [69]. Second, PBL explicitly emphasizes self-directed learning skills – if students cannot identify areas of discussion in the case vignettes, no discussion will occur [70]. Third, PBL facilitates the development of teamwork, interpersonal, and communication skills [67, 69]. Students need to work collaboratively and effectively for PBL sessions to be successful, and these skills are clearly important for success in clinical practice.