



# The Science of Learning and Art of Education in Cardiology Fellowship

REVIEW

**NATALIE STOKES, MD** 

**KATHRYN BERLACHER, MD, MSC**

\*Author affiliations can be found in the back matter of this article

HOUSTON  
**Methodist**<sup>®</sup>  
DEBAKEY HEART &  
VASCULAR CENTER

## ABSTRACT

The science of learning, bolstered by the foundational principles of adult learning, has evolved to allow for a more sophisticated understanding of how humans acquire knowledge. To optimize learning outcomes, cardiology educators should be familiar with these concepts and apply them routinely when teaching trainees. This paper presents an overview of the neurobiology of learning and adult learning principles and offers examples of ways in which this science can be applied in cardiology fellowships. Both fellows and educators benefit from the science of learning and its artistic application to education.

## CORRESPONDING AUTHOR:

**Kathryn Berlacher, MD, MSc**

University of Pittsburgh  
Medical Center, Pittsburgh,  
Pennsylvania, US

[berlacherk@upmc.edu](mailto:berlacherk@upmc.edu)

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## BACKGROUND

Cardiology fellowship remains one of the most competitive matches in the nation, and for good reason. The field of cardiology is constantly evolving with extensive scientific discovery and innovative care delivery, which makes training in this area both exhilarating and challenging. The demands on cardiology trainees and educators necessitate the optimal use of time and resources to achieve target learning outcomes.

The science of learning has grown tremendously in the past few decades. Research demonstrates that learning is an active process that directly changes the architecture of the brain.<sup>1</sup> New concepts surrounding learning provide an opportunity to optimize the educational processes in cardiology fellowship and enhance durable learning for cardiology fellows. Herein we introduce the basics of the science of learning and adult learning theories and provide creative ways for educators to enrich training in cardiovascular fellowship so that the field and our care of patients continue to improve.

## THE SCIENCE OF ADULT LEARNING NEUROBIOLOGY OF LEARNING

The process of learning involves structural and functional synaptic changes in the central nervous system.<sup>1-3</sup> Multiple distinct components of neurons demonstrate use-dependent plasticity.<sup>4</sup> Data suggests that specific synaptic and nuclear signaling events facilitate acquisition and retention of information.<sup>5</sup> Improved efficiency in synaptic transmission has been associated with several mechanisms of knowledge construction, including increased neuronal connectivity, faster conduction, improved blood flow to distinct areas of the brain via angiogenesis, and new and strengthened synaptic connections.<sup>6-14</sup>

Synaptic modifications have been directly linked to behavioral learning processes in animal models.<sup>10,11</sup> Human studies using pathology and functional brain imaging have established that different types of learning stimulate different parts of the brain, and distinct parts of the brain are activated when we attempt to retrieve knowledge.<sup>14-18</sup> Although a great deal remains to be known about the neurobiology of learning, research has established that the brain has the potential for continual development and undergoes reorganization through the process of learning.<sup>1</sup>

### Cognitive Load Theory

Adults learn, or acquire actionable knowledge, by processing new information and relating it to previously attained knowledge. Cognitive load theory (CLT) identifies two distinct structures of memory that interact with one

another during learning: *working memory*, where we hold and process new information, and *long-term memory*, where we store information we have learned.<sup>19,20</sup> Working memory has a limited capacity at any given time, while long-term memory has unlimited capacity, which allows us to remember things from the past. The brain learns by moving information from working memory to long-term memory. CLT postulates that this process depends on how information is presented and the complexity of the information itself. Total cognitive load is made up of *intrinsic load*, the content to be learned, and *extrinsic load*, how the content is presented. Working memory is confronted with the total cognitive load; thus, if high effort is required to process the extrinsic load, there are less available resources for processing intrinsic load.<sup>19-23</sup> In other words, the harder a learner has to work to process *how* information is presented, the less memory the learner has available to process the content itself. Educators can improve learning outcomes by limiting extrinsic load so that learners can convert working memory to long-term memory with less effort.

### Sensory Processing

Traditionally it was believed that individuals have different learning styles that help them learn the best; for instance, some are visual learners, while others learn best by audio input. Despite being repeatedly discredited, the myth that individuals have distinct learning styles persists in much of medical education.<sup>24</sup> Yet research demonstrates that adult learners learn best by active involvement with material via multiple sensory pathways.<sup>19,24-26</sup> Imaging studies show that the brain responds to novel information with heightened awareness,<sup>1</sup> and functional neuronal changes are enhanced when the learner is actively engaged.<sup>27</sup>

Providing access to the same information using multiple sensory pathways, a process known as *dual coding*, enhances learner attention, motivation, and retention.<sup>24,28</sup> Combining words with visuals, for instance, provides greater impact than use of either modality alone. Likewise, the act of writing new content integrates kinesthetic activity with audiovisual presentation of information and optimizes learner attention through participation.<sup>26,29</sup>

### Environment and Stress

Memory formation is situational and strongly influenced by the learning environment, including how safe and how stressed the learner feels in a given setting. A sense of safety allows for receptivity to learning; in fact, studies demonstrate that a learner's motivation and creativity in problem solving increase when they feel safe in the educational environment.<sup>30,31</sup> However, a safe and

optimized learning environment does not mean a stress-free environment. A small amount of stress prompts a neurohormonal cascade of increased dopamine levels with subsequent cortisol release that has been shown to rapidly engage and enhance hippocampal and amygdaloid processing, accounting for enhanced memory construction.<sup>32</sup> Too much stress, though, results in bad memory formation, likely due to the suppression of prefrontal cortex processing.<sup>33</sup> The Yerkes-Dodson Law Bell Curve, a century-old model displaying a bell-shaped curve relationship between stress and memory formation, has borne out in both animal and human models.<sup>33,34</sup>

### Repetition and Retrieval

The term *deliberate practice* refers to effortful practice, beyond merely time and exposure, that is demonstrated to achieve expertise in any given field. It is specific and structured with interval increases in complexity of knowledge and skill formation. Provision of immediate and frequent feedback and opportunities for repeated performance to refine behavior are necessary.<sup>35</sup> The pacing and spacing of repetition are as important as the practice of repetition itself. Spaced practice has robust support in the literature for strengthening long-term memory formation when compared with compressed

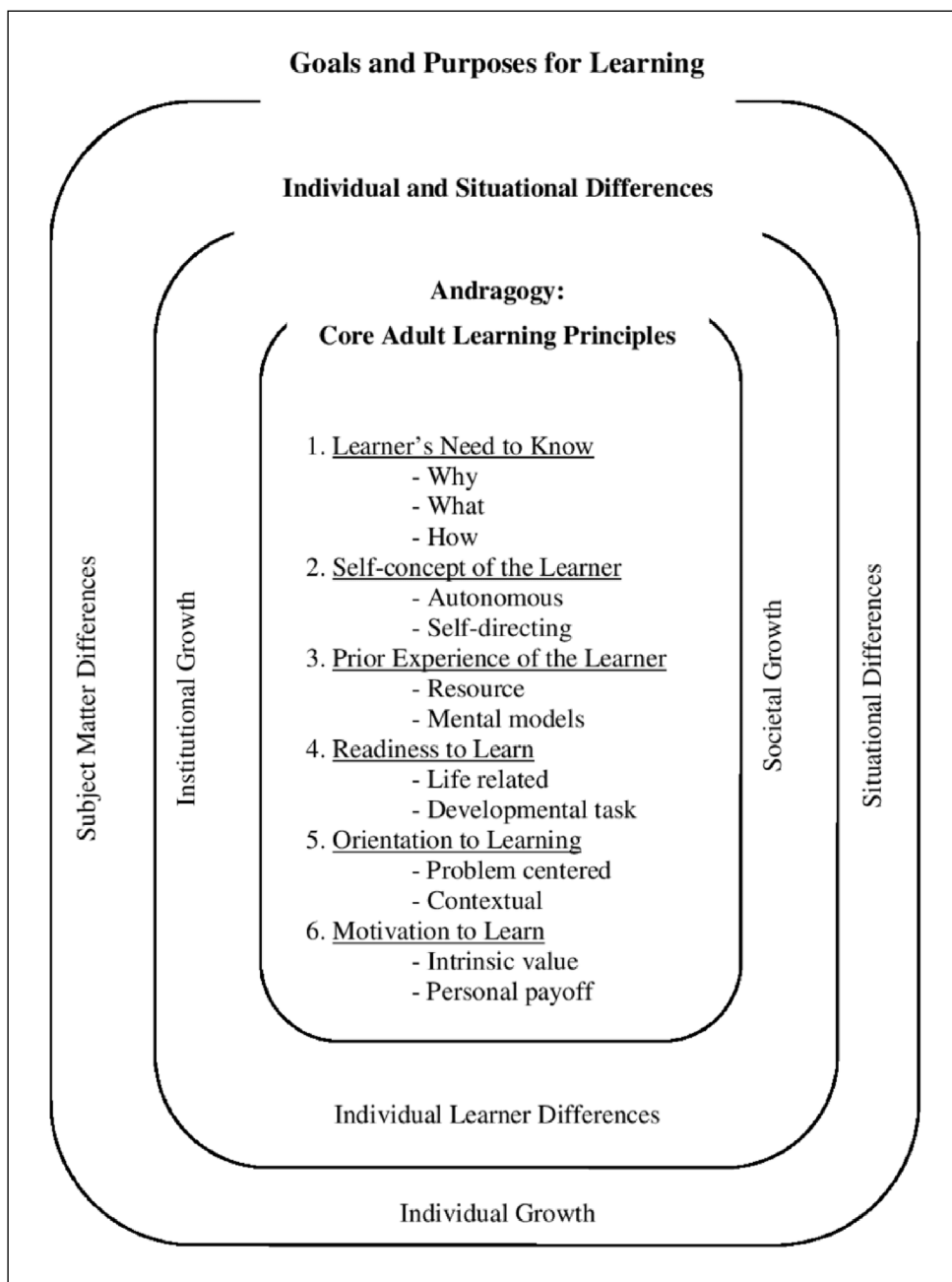


Figure 1 Andragogy in practice model. Reproduced with permission from Knowles et al.<sup>45</sup>

learning, showing advantages in basic memory tasks, complex conceptualization, and motor skill acquisition.<sup>36-38</sup> The process of interleaving, or studying related skills or concepts in parallel, has likewise demonstrated to improve learning.<sup>37</sup> Retrieval practice involves attempting to recreate what was previously learned prior to engaging with the material once again. This skill is shown to strengthen long-term memory formation.<sup>39-41</sup> Optimal deliberate practice engages repeated activation of neuronal pathways with spaced trials, interleaving, and retrieval practice.

### Reward and Reinforcement

The brain has an intrinsic reward system that reinforces behaviors when activated.<sup>42</sup> Importantly, the reward of achieving a goal can have the same effect as a more tangible award, such as a prize or money.<sup>43</sup> The brain is constantly engaged in the process of determining relative value of short-term versus long-term rewards. When an adult can see the benefits of learning within the context of larger goals, they are more engaged in the process.<sup>1</sup> As noted, feedback is an essential part of deliberate practice and can be used to optimize the intrinsic reward system and reinforce positive behaviors.<sup>44</sup>

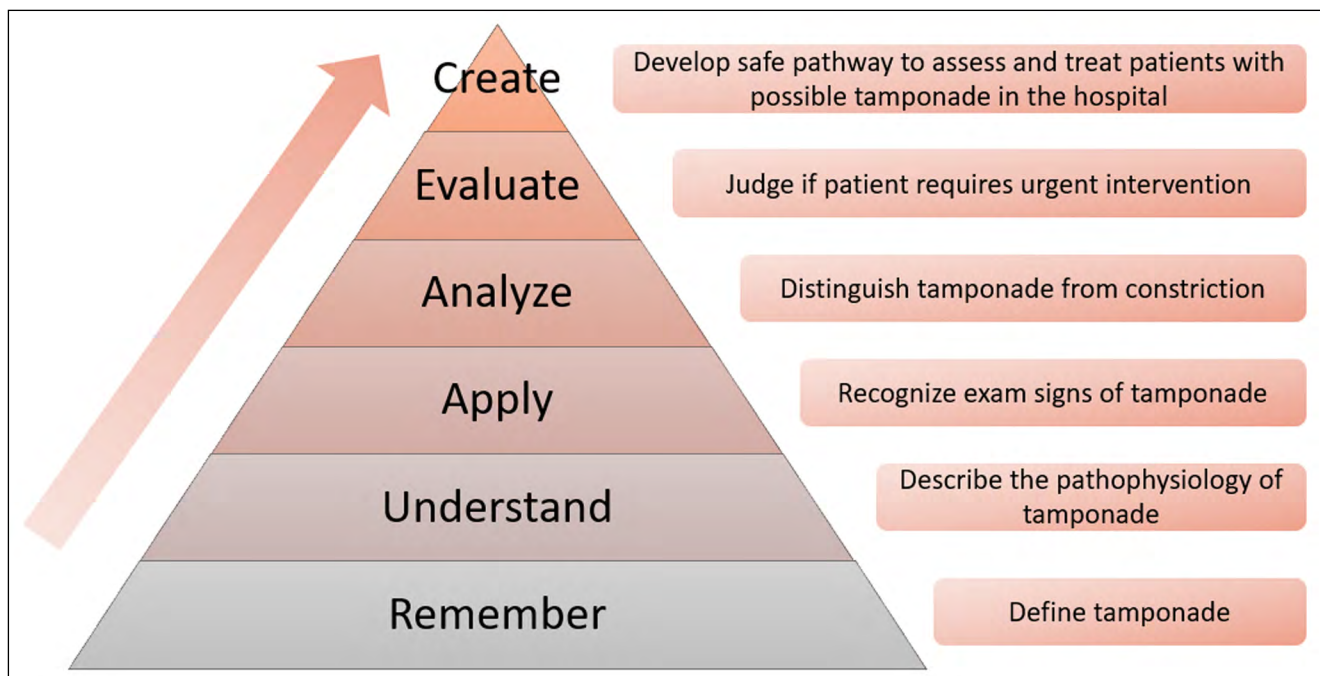
### ADULT LEARNING PRINCIPLES

The neurobiology of learning coincides with the development of adult learning principles. These principles translate science into action by providing a foundation for effective teaching. The term “andragogy” was first coined by Malcolm Knowles in the 1970s to differentiate

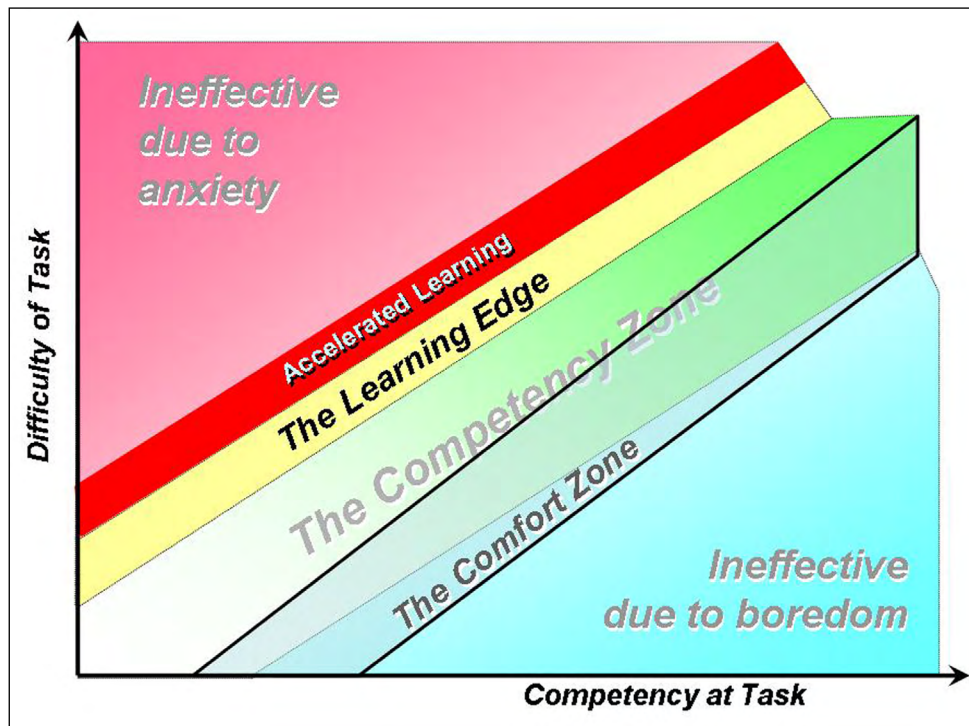
adult learning from “pedagogy” or childhood learning.<sup>45</sup> Knowles outlined six key learning principles that serve as the foundation of adult learning (Figure 1). These principles establish that experience provides the basis for adult learning; adults need to be involved in planning and evaluating their own instruction and are most interested in learning subjects that have immediate relevance to them.<sup>46</sup>

Benjamin Bloom, in collaboration with other educational scholars, established a framework for categorizing educational goals. Known as Bloom’s taxonomy, it consists of categories of successive skills that make up a continuum of cognitive learning (Figure 2).<sup>47</sup> Recent adaptations include a change in terminology from noun to verb forms and an expanded 2-dimensional framework.<sup>48</sup> Bloom’s taxonomy is a useful tool in designing and assessing educational curricula.

While not established as a traditional adult learning principle, the concept of the “learning edge” is an optimal adaptation of the aforementioned Yerkes-Dodson Law in practice. Given the unique relationship between stress and knowledge construction, this framework operationalizes the ideal zone of anxiety for knowledge formation. By plotting difficulty of a task versus capability, a competency zone evolves (Figure 3). Accelerated learning can occur in this zone, provided the learner is not overly stressed. The learning edge is the point at which a learner is mentally stimulated and challenged, outside of their comfort zone, but still within an environment where they feel unthreatened.<sup>49</sup>



**Figure 2** Revised Bloom’s taxonomy with cardiology specific example. Adapted with permission from Krathwohl D.<sup>48</sup>



**Figure 3** The Comfort Zone and the Learning Edge. Reproduced with permission from Armour.<sup>49</sup>

## THE ART OF EDUCATION

With a more sophisticated understanding of learning, cardiology educators should feel prepared to operationalize these concepts in their day-to-day practice. This science and the principles of adult learning should guide cardiology education across all learners, at all levels, for all rotations in all curricula. In this section, we discuss the art of education, which in essence is the creative application of the science of learning.

Prior to this application, certain fundamentals must be established for fellows to flourish and for education to succeed. First, educators must create a supportive learning environment where fellows can safely address their vulnerabilities and shortcomings and engage in active problem solving. Second, educators should be transparent about the science of learning. Incorporating metacognition—teaching fellows how and why they learn—early in training urges them to capitalize on all learning opportunities and, as outlined below, enhance their independent learning. If fellows know why certain methods are used, they are more likely to participate in the process. Finally, educators must embrace the concept that their role is more closely aligned with that of a facilitator than with owner or distributor of knowledge. Below we provide examples of where and how educators can artistically apply the science of learning in a variety of settings throughout fellowship training.

## CONFERENCE SETTINGS

Larger conferences—including grand rounds, journal clubs, and noon conferences—are a mainstay of fellowship education. To optimize these sessions for learning, educators can take some relatively simple steps. First, to help fellows manage intrinsic load, educators should embrace a “content diet.” Key learning objectives should be limited and clearly stated from the start and then repeated at the end of each conference. While it is tempting to be comprehensive about topics when leading a conference, CLT teaches us that providing more material can often be detrimental to true learning given the limited capacity of our working memory. Content that does not directly support stated objectives can be provided as reference material for fellows to review at other times.

Incorporating ways for fellows to be interactive is essential for them to remain attentive and engaged during conferences. While passive didactic lectures increase short-term retention, they are not associated with long-term learning since adults learn better by doing, as noted by Knowles. One simple method of conference interaction proposed by Doug Lemov is “Think-Pair-Share.”<sup>50</sup> In this approach, fellows are asked to think about a prompt or question. Then they pair with a co-fellow to share their thoughts before reconvening with the entire group. Asking fellows to discuss their thoughts encourages greater participation, builds confidence and creativity in problem solving, and leads to deeper understanding.

**Educator tips:**


1. **Less is more.**
2. **Interaction increases learning.**

**CLINICAL ROTATIONS**

Much of learning in cardiology fellowship happens spontaneously, such as on rounds, at the bedside, in the echo lab, and alongside the many day-to-day activities that take place throughout training. One way of augmenting learning in these moments is to engage fellows in simple gamification. Gamification applies the standard elements of game playing (ie, badges, levels, leaderboards) to learning and training. While adding a little fun to the workday, gamification also creates a safe learning environment by making failure less risky for fellows. Educators can identify gaps in knowledge without the fellow feeling uncomfortable. Additionally, with competition at play, there is release of dopamine that increases knowledge retention. For example, on the cardiology consult rotation,

educators can start the day by asking every member of the team to state one cardiac-related point they learned in the past 24 hours. An appointed medical student can keep track of all learning points throughout the week. At the end of the week, the team can review those points and vote on three favorites. The team members responsible for those points receive bragging rights...and possibly also coffee from the attending that afternoon! As noted, both spaced retrieval (ie, recalling a learning point from the day prior) and repetition with spaced intervals (ie, reviewing points at the end of the week) are important for long-term memory formation.<sup>36-41</sup> Alternatively, an educator can create a quick game of “Heart Bingo” at the start of the week, filling each box with a cardiac-related activity. Members of the team work to complete these activities throughout the week, and the first person to complete an entire row, column, or diagonal wins (Figure 4).

**Educator tip: Play more, learn more.**

	H	E	A	R	T
H	Diagnose AVNRT	Identify CVP waveform	Teach session on vasopressors and inotropes	Calculate Fick cardiac output	Listen for pulsus paradoxus
E	Recognize cannon A waves	Estimate JVP accurately	Evaluate femoral site for hematoma	See B lines on lung ultrasound	Identify prolonged QT
A	Assess severity of AS by auscultation	Prescribe adenosine		Visualize Impella with point-of-care ultrasound	Place hemodialysis catheter
R	Perform ACLS	See Torsades de Pointes	Identify left anterior fascicular block	Adjust ventilator settings	Teach session on intra-aortic balloon pump
T	Obtain 4 standard windows on cardiac ultrasound	Place pulmonary artery catheter	Palpate displaced point of maximal impulse	Identify Brugada syndrome	Treat cardiorenal syndrome

**Directions: Complete activities in boxes. You win when an entire row, column, or diagonal is complete and signed off by attending!**

**Figure 4** Example of gamification: HEART Bingo for the cardiac critical care unit. AVNRT: atrioventricular nodal reentry tachycardia; CVP: central venous pressure; JVP: jugular venous pressure; AS: aortic stenosis; ACLS: advanced cardiac life support

## ACQUIRING NEW SKILLS

Almost everyone in medicine is familiar with the old motto “see one, do one, teach one.” Yet every cardiologist who has been in a complex percutaneous intervention knows that teaching such procedures is not that simple. A new six-step framework of training procedural competency has been developed by Taylor Sawyer and colleagues using advancements in the science of learning: learn, see, practice, prove, do, and maintain.<sup>51</sup> The first two steps provide fundamental knowledge and observation of the skill prior to introduction of psychomotor acquisition. Importantly, initial practice for skill development is often performed in a simulated setting where repetitive practice is allowed before fellows prove they are ready to perform the behavior in a clinical setting. All patient interactions must be done under direct supervision with support and guidance as fellows progress to independent practice. Maintenance of skills is achieved by continuous clinical practice and, if necessary, supplementation with simulation-based training.

Feedback is an essential part of skill acquisition for a cardiology trainee. Recently called into question is a commonly taught method of feedback, the “sandwich approach,” wherein the educator provides one constructive or negative piece of feedback sandwiched between two positive comments. This ineffective means of giving feedback, as discussed in many business articles and blogs, undermines both the content of the feedback and the relationship educators have with fellows.<sup>52</sup> A better feedback framework is Ask, Tell, Ask.<sup>53</sup> First, the fellow is asked to name one thing they did well and one thing they could do better. Second, the fellow is told how they did, using specific behavior-based examples. Finally, the fellow is asked to postulate specific ways they can improve, making an action plan together with the educator.

**Educator tip: Give feedback on observed skills and then repeat, repeat, repeat.**

## DAILY FELLOW ROUTINES

To attain competency in cardiology and to continue that competency for the duration of a career, fellows must practice routine and effective skills for independent learning during training. Passive reading and reviewing content for hours rarely translates to significant retention. Fellows should be encouraged to find ways to make content and concepts stick. Thus, educators should deliberately discuss and model practices that lead to effective learning. As noted, the simple kinesthetic activity of using a pen and paper to write down learning points activates multiple sensory pathways, allowing for increased likelihood of

retention.<sup>26,29</sup> Educators should write things down when encountering new content and ask fellows to do the same.

If facilitating board preparation sessions, educators should integrate multiple areas of cardiology rather than covering a single topic. This incorporates the concept of interleaving. When planning noon conferences and grand rounds schedules, revisit topics frequently to allow for spaced repetition. Before revisiting topics, fellows should be encouraged to recall what has been previously taught on the topic, fostering retrieval practice. This can be done both in group sessions and at home when the fellow is independently studying. Finally, fellows should be inspired to climb Bloom’s taxonomy pyramid regarding the content being learned (Figure 2). Evaluation and creation of cardiology concepts are the primary goals for fellows during training.

**Educator tip: Form habits that make concepts stick.**

## CONCLUSION

As the fields of cardiology and education science evolve, informed and inventive educators need to be at the helm of cardiology training. Advances in the science of learning provide a wealth of opportunity to enhance education during cardiology fellowship. When education is done well, the acquisition of cardiac knowledge is more consistent and efficient, benefitting not only fellows but also our patients.


## KEY POINTS

- Advances in understanding the neurobiology of learning provide foundational structure for adult learning theories.
- The principles of adult learning theory should guide education of all learners in all contexts during cardiovascular fellowship.
- The art of education is in the application of the science of adult learning.
- A supportive learning environment and metacognition are required when optimizing learning outcomes.
- Multiple opportunities exist to optimize education in cardiology fellowship, including during conferences, on rounds, when teaching new skills, and when structuring independent learning.

## COMPETING INTERESTS

The authors have no competing interests to declare.

## AUTHOR AFFILIATIONS

**Natalie Stokes, MD**  [orcid.org/0000-0003-3562-7682](https://orcid.org/0000-0003-3562-7682)  
University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, US

**Kathryn Berlacher, MD, MSc**  
University of Pittsburgh Medical Center, Pittsburgh, Pennsylvania, US

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