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4 Anesthesiology has been transformed by progress on multiple fronts. What was once among the
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6 most dangerous aspects of medical care, with mortality rates as high as 1 in 2,000 in the early
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8 decades,¹ has become a model of systematic safety, achieving perioperative mortality rates below
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10 1 in 100,000.² Training environments that once demanded hundred-hour weeks now protect
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12 resident wellbeing through work hour restrictions.³ Hierarchical cultures that tolerated abuse
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14 have given way to more humane, supportive learning environments. Standardized competency
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16 frameworks ensure minimum thresholds for practice.⁴ Sophisticated technology augments
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18 clinical decision-making, and the specialty has seen efficiency gains throughout the perioperative
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20 system.
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27 Each of these developments represents genuine progress toward values the profession has rightly
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29 embraced: patient safety, trainee wellbeing, humane culture, standardization, and efficiency. This
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31 article does not argue against any of them. But here is the tension: these improvements, however
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33 valuable, have collectively reshaped the learning environment in ways that erode the cognitive
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35 conditions required to develop adaptive expertise. Protocols that reduce error also reduce the
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37 effortful reasoning that builds clinical judgment. Technologies that augment decision-making
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39 can shortcut the deep processing through which novices develop durable knowledge. Production
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41 pressures that maximize efficiency crowd out the reflective practice and supported struggle that
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43 expertise demands. The conditions that cognitive science identifies as necessary for expertise
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45 development⁵⁻⁷ have been incidentally optimized away, not through malice or error, but through
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47 the cumulative effect of solving other problems extremely well. Importantly, this argument does
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49 not depend on the presence or absence of clinical complications or errors; the cognitive
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51 conditions we describe in this paper – desirable difficulty, reflective practice, deliberate
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53 challenge, and epistemic growth – operate independently of whether adverse events occur.
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Adaptive expertise is the capacity to improvise, synthesize, and exercise judgment when protocols fail, novel situations arise, or technology is unavailable. It is distinct from routine competence, which is the ability to perform effectively under familiar conditions using established procedures. Modern training systems are optimized for the latter. As Baker⁷ has argued, the Accreditation Council for Graduate Medical Education (ACGME) milestones designate competence as the graduation requirement and, despite aspirational language, do not require the development of expertise. When the explicit outcome for completion of training is simple competence, the system's implicit message, regardless of intent, is that adequacy is the destination.

If we value adaptive expertise, we must now cultivate it deliberately. Doing so requires understanding what expertise demands: cognitive architecture built through effortful encoding, reflective practice supported by continuity and feedback, deliberate practice at the edge of competence, and epistemic sophistication, a shift in how practitioners relate to knowledge and uncertainty. We must examine how our current systems, optimized for patient safety, trainee wellbeing, institutional efficiency, cultural humanity, and educational standardization, can be adjusted to provide adaptive expertise. To reiterate from the outset: this article does not argue for a return to training conditions that were less safe for patients or less humane for trainees. The advances of recent decades are genuine and worth preserving. The question is how we can preserve those advances while also rekindling, through deliberate design, the conditions that expertise requires.

What Builds Expertise

To examine how modern training environments may affect expertise development we must establish what cognitive science tells us about how expertise forms. **Four conditions emerge as essential: cognitive architecture built through effortful encoding, reflective practice supported by continuity and feedback, deliberate practice at the edge of current competence, and epistemic sophistication—a mature relationship with knowledge and uncertainty. Each is explored below.**

Expertise is characterized not just by what clinicians know,⁶ but by how that knowledge is organized. Experts develop rich cognitive architecture, including mental schemas and "illness scripts" that allow rapid pattern recognition.⁸ This architecture develops through effortful encoding. The concept of "desirable difficulties" describes the counterintuitive finding that learning conditions which make initial acquisition harder often produce more durable and transferable knowledge. When learners must struggle to retrieve information, generate solutions before receiving answers, or work through problems without immediate guidance, they build stronger cognitive scaffolding than when the path is easy.⁹⁻¹¹

Second, expertise requires reflective practice. Schön distinguished between reflection-in-action (the ability to think about what one is doing while doing it, adjusting in real time) and reflection-on-action (the post-hoc analysis that integrates new lessons into existing mental models). Both require time and continuity: the opportunity to observe how decisions unfold and to process those observations deliberately.^{12,13} Expert faculty physicians can guide both processes, helping trainees identify learning moments in real time and creating environments that allow for reflection-on-action.¹⁴

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4 Third, expertise requires deliberate practice: focused work at the edge of current performance,
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6 with clear goals, immediate feedback, and opportunities for repetition and refinement. This is
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8 distinct from mere experience. A clinician can accumulate years of practice without developing
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10 expertise if that practice occurs entirely within a comfort zone, buffered from the cognitive
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12 demands that drive growth.¹⁵⁻¹⁷ Simply gaining skills or factual knowledge does not itself confer
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14 expertise; the formation of expertise requires motivation to improve, a focus on clearly defined
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16 tasks, building upon useful feedback, and deliberate practice with the specific aim of improving
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18 performance.
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24 Finally, expertise involves epistemic development, the transition from viewing knowledge as a
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26 collection of certain facts to understanding it as a process of weighing evidence and context to
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28 reach the most justifiable conclusion. Novices tend toward an absolutist epistemology: there is a
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30 right answer, and the goal is to find it. Experts develop comfort with uncertainty, understanding
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32 that medicine operates in probabilities and that clinical judgment means navigating gray zones
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34 where guidelines may not clearly apply. This epistemic sophistication may be the defining
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36 feature of the master clinician.^{8,18}
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43 These four pillars – cognitive architecture, reflective practice, deliberate practice, and epistemic
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45 sophistication – predict what will happen when the conditions that build them are systematically
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47 reduced: expertise development will slow, even as the attainment of competence remains
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49 achievable. While it is true that we lack longitudinal data comparing adaptive expertise across
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51 training eras (such studies would be methodologically complex), if these principles are valid and
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53 we value expertise, we must examine whether our current systems adequately preserve the
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55 conditions needed to promote expertise.
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Structural Impediments to Expertise Development in the Modern Learning Environment

As illustrated in Figure 1, the very advancements that have improved patient care and the training experience (safety, technology, systems, and culture) exert unintended downward pressure on the learning environment. Rather than examining these modernizations in isolation, we must look at how they collectively erode the four cognitive pillars required for expertise. Table 1 maps how these systemic threats undermine each pillar, providing a framework for understanding how well-intentioned improvements starve the developing mind of the ingredients it needs to grow.

Impaired Cognitive Architecture Development

Modern anesthesiology has developed an impressive array of tools that reduce cognitive burden. Standardized protocols like Enhanced Recovery After Surgery pathways minimize variation and error. Sophisticated monitoring systems provide increasingly advanced alarms and embedded diagnostics. Newer pharmacologic agents like sugammadex and remimazolam offer rapid, reliable solutions where older approaches required nuanced titration and deeper physiological understanding. Decision support systems and artificial intelligence (AI) tools promise to further augment (or replace) elements of clinical reasoning. Meanwhile, answers to many common clinical questions are instantly accessible through UpToDate, Google, OpenEvidence, and MDCalc.

Each advance serves the important goals of safety, efficiency, and reliability. But each also represents cognitive offloading. When a protocol specifies the approach, a physician need not reason through the decision. When learners consult AI tools before thinking critically, the process of deeply interpreting clinical questions is bypassed. Studies show that when tools handle

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4 cognitive tasks, the effortful encoding that builds cognitive architecture is cut short.¹⁷

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6 Experimental evidence supports this concern: Grinschgl et al.¹⁹ demonstrated that cognitive
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8 offloading improves immediate task performance but diminishes long-term memory formation,
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10 and Dahmani and Bohbot²⁰ showed that habitual GPS use causes dose-dependent decline in
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12 spatial memory, a compelling analogy for clinical decision support. In medical education
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14 specifically, a recent systematic review found that AI tools cause both deskilling in trained
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16 practitioners and “never-skilling” in students who bypass foundational learning entirely,²¹ and a
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18 randomized controlled trial demonstrated that misleading AI degraded novice diagnostic
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20 accuracy while correct AI offered no measurable improvement in users’ development.²² A
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22 possible counterargument holds that offloading routine cognition to external tools frees cognitive
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24 resources for higher-order reasoning. This may be true for the extant expert, whose foundational
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26 knowledge is already consolidated and who uses decision support to extend rather than replace
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28 their own thinking. But the novice who consults these tools before engaging in clinical reasoning
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30 never builds the architecture that would allow such extension, leading to a “deskilling” effect in
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32 fundamental knowledge and skills. The tool becomes a substitute for thought rather than a
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34 scaffold for it. In other words, the developmental sequence matters: one cannot offload what one
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36 never possessed.
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46 Beyond offloading cognitive work, the universal availability of information itself may affect
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48 what trainees encode into long-term memory. Research on cognitive offloading and transactive
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50 memory systems suggests that when information is readily accessible externally, individuals are
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52 less likely to commit it to memory and more likely to mistake accessible knowledge for
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54 possessed knowledge.^{23,24}
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Disrupted Reflective Practice

Work hour restrictions were implemented to reduce fatigue-related errors and improve trainee wellbeing^{25,26}. But, when trainees hand off patients mid-course, their ability to personally observe the downstream consequences of their decisions is objectively decreased, and reflection-on-action becomes more difficult. This fragmentation may also erode the sense of ownership that motivates deep engagement with cases. Production pressure compounds these effects.

Anesthesiology departments face intense pressure to maximize operating room throughput and clinical revenue, leaving little time for the post-case conversations where faculty and trainee process what happened and what could have been improved.

Reflection also depends on honest input. The movement toward polite training environments has dismantled abusive hierarchies, a genuine improvement, but has also made many faculty reluctant to deliver direct critique.^{27,28} Trainees who rarely receive critical feedback are at risk of interpreting its absence as validation.²⁹

Constrained Deliberate Practice

Deliberate practice requires working at the edge of one's competency with real stakes. Several forces constrain these opportunities. Perceived medicolegal and safety pressures have created powerful incentives for defensive supervision.^{30,31} Attendings, concerned about these issues, may intervene earlier than when educational considerations would indicate are optimal. Adequate supervision is non-negotiable for patient safety, but the learning moments that matter most – where trainees must integrate knowledge under pressure and make rapid decisions with real consequences – often occur precisely when the temptation to take over is strongest. Production

pressures, in addition to patient satisfaction metrics, amplify this, and create an environment where taking over from a struggling trainee is often the easy choice. Because deliberate practice requires operating at the inefficient edge of one's current skill set, the drive for operating room efficiency often incentivizes both learner and educator to retreat to 'tried and true' methods. While this ensures case progression, it effectively confines trainees to their comfort zones, risking stagnation at the level of basic competence rather than progression toward mastery. The assumption that sheer volume of clinical experience compensates for these constraints is not supported by the evidence. Ericsson³² demonstrated that experience-based indicators (years in practice, case volume) show weak correlation with actual clinical performance, and a systematic review by Choudhry et al. found that in over half of 62 studies examined, physician performance actually decreased with more years of experience,³³ underscoring that experience without deliberate challenge produces stagnation, not growth.

Thwarted Epistemic Development

Ironically, some of the largest movements in medical education itself may impede the epistemic development of trainees.

Current assessment practices likely reinforce novice epistemology. The heavy reliance on multiple-choice question (MCQ) examinations (for board certification, in-training evaluation, fellowship selection, and maintenance of certification) is psychometrically defensible and provides standardized, scalable assessment of factual knowledge. As Parekh and Bahadoor have noted, MCQs primarily assess the lower levels of Miller's pyramid ("knows" and "knows how") rather than the clinical reasoning and judgment that define expertise.³⁴ But over-reliance on this modality implicitly teaches that clinical medicine consists of discrete questions with correct

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4 answers. This has also unfortunately transformed the way that young physicians approach
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6 learning. Question banks have become a dominant study modality, training learners to pattern-
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8 match question stems and memorize associations rather than reason through problems,
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10 optimizing for recognition over reasoning. While formal study of trainee learning behaviors is
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12 limited, the authors' **cumulative** experience with almost 40 years leading residency programs
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14 over the last 25 years suggests a marked shift toward question-bank dominance as a primary
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16 study modality. The epistemic sophistication required to navigate genuine uncertainty, where
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18 evidence is incomplete and the best path depends on context, values, and probability, is relatively
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20 devalued.
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27 Didactic habits, heavily influenced by learner preferences rather than outcomes, have also shifted
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29 toward cognitive ease. The proliferation of podcasts and curated digital summaries offers a
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31 frictionless learning experience that trainees understandably prefer. However, this cognitive ease
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33 creates a metacognitive trap. Research demonstrates that passive consumption often generates
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35 inflated 'judgments of learning' (i.e., learners mistake the fluency of the presentation for their
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37 own mastery of the content).³⁵ While this creates a satisfying sense of immediate understanding,
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39 it rarely tracks with higher-level outcomes like deep understanding or behavioral change. When
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41 knowledge is consumed without the struggle of synthesis, it remains superficial, available for
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43 recognition on a multiple-choice examination, perhaps, but inaccessible for complex clinical
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45 improvisation.
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53 The emerging framework of competency-based medical education (CBME) may also pose issues
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55 for epistemic sophistication. CBME was designed to ensure graduates meet minimum standards
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57 and represents a desire for meaningful improvement in accountability and safeguards for
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4 patients^{36,37}. However, the nomenclature itself presents a hazard. By defining “competence” as
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6 the explicit outcome, the framework risks linguistically and structurally signaling that adequacy
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8 is the destination. Trainees coming from medical schools that simply assign pass or fail grades
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10 may already have a mindset that competence, and not excellence, is the desired goal. While
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12 CBME aims to successfully safeguard the “floor” of practice, eliminating incompetence and
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14 identifying struggling learners,³⁸ it inadvertently suggests that development beyond this
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16 threshold is not valued. As Baker has argued, the ACGME milestones explicitly designate
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18 competence as the graduation requirement; despite aspirational language about higher levels of
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20 achievement, the framework does not require – or encourage – the development of expertise.⁷
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26 Proponents of CBME would rightly note that the framework was never intended to define
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28 competence as the ceiling of achievement; competency milestones lay out a framework to
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30 distinguish between simple competence and aspirational expertise.³⁸ While true in principle,
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32 educational frameworks communicate through structure and nomenclature as much as through
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34 stated intent. When the explicit requisite outcome for completion of training is simple
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36 competence and when time-variable training allows early graduation upon demonstration of
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38 adequacy, the implicit message and incentive, regardless of intent, is that meeting only the
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40 minimum standard is the goal. What a system measures and rewards will shape what learners
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42 pursue.^{39,40}
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49 Lastly, and more fundamentally, the very systems that have made anesthesiology safer may
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51 inadvertently reinforce a novice epistemology. Protocols imply right answers. Checklists suggest
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53 completeness is achievable. This architecture, valuable for standardization and ensuring the floor
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55 is met, does not cultivate the expert's relationship with uncertainty: the understanding that
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57 guidelines are probabilistic and population-based, that medicine is irreducibly complex, that the
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4 hard cases are hard precisely because the right answer is not knowable in advance. When trainees
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6 are rarely asked to navigate true ambiguity, when the system always provides the path, the
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8 epistemic sophistication that defines mastery may not develop.
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10 11 12 13 **Design Principles for Expertise Development** 14

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16 If expertise will not emerge automatically from modern training, we must deliberately design
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18 training to ensure its development if we want it. This means building educational experiences
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20 that address each pillar – cognitive architecture, reflective practice, deliberate practice, and
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22 epistemic sophistication – while preserving the gains of our optimized systems. Table 1 maps
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24 specific threats to restorative strategies; below, we organize those strategies by who can act.
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29 At the learner level, trainees have substantially more agency than they may recognize. The
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31 process begins with the fundamental motivation to attain expertise, a deliberate choice to pursue
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33 mastery rather than settling for the competence that some educational systems target. This
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35 commitment necessitates a pivot in study habits: actively resisting the superficial, fragmented
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37 approach fostered by question banks and instead committing to cognitive methods (e.g.,
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39 generative retrieval, elaborative interrogation, comparative case analysis) that promote deep
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41 retention and transfer. During clinical work, learners should formulate differential diagnoses and
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43 anesthetic plans before consulting decision support tools. **When learners do consult AI-based**
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45 **decision support, they should critically evaluate its output: examining the cited literature,**
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47 **identifying potential biases or gaps in reasoning, comparing responses across tools, and asking**
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49 **whether the recommendation accounts for the specific clinical context rather than accepting it as**
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51 **authoritative.** They must also deliberately seek out cognitively challenging topics, for example
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53 choosing a less comfortable technique precisely because it is less comfortable. Additionally,
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4 learners should actively solicit feedback, embracing a learning orientation that values growth
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6 over the appearance of competence. Finally, following patients longitudinally can close the
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8 feedback loop that fragmented care disrupts.
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12 At the educator level, faculty members must view their role not merely as supervisors but as
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14 architects of challenge and mentors that promote mastery or expertise. This means structuring
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16 learning experiences that demand reasoning before consultation: exploring "what if" scenarios
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18 during cases, embracing preoperative discussions as unhurried opportunities to explore clinical
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20 thinking by asking residents to articulate their plans and rationales before revealing the
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22 educator's own. Educators must also function as visible safety nets while resisting the impulse to
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24 immediately take over when residents struggle, allowing supported difficulty to do its
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26 developmental work. Critically, developmental feedback must be restored as a norm, delivered
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28 with respect and genuine investment in the learner's growth.²⁸ Lastly, educators can model
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30 epistemic sophistication explicitly, saying "I don't know, but here's how I'm thinking about it,"
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32 demonstrating that expertise means navigating uncertainty rather than eliminating it.
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41 At the program and institutional level, educational design must protect what daily pressures
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43 erode. Case ownership and longitudinal follow-through should be prioritized wherever possible,
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45 preserving the continuity that reflection requires. Culturally-expected debriefing and structured
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47 post-case conversations should be institutionalized as an expectation rather than as an aspiration.
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49 Curricula should include dedicated reflection training, strengthened longitudinal mentorship, and
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51 deliberate exposure to cases where guidelines conflict or evidence is thin. High-fidelity
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53 simulation can be leveraged not just for procedural skills but to force trainees to confront
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55 uncertainty and integrate multiple data streams simultaneously. Programs should move beyond
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competency checklists toward mastery-based frameworks that explicitly reward integrative judgment and synthesis. And departments must weigh both educational outcomes and clinical expertise of trainees alongside the traditional throughput and academic metrics in faculty evaluation and promotion.

At the specialty level, we must align assessment with what we claim to value. The heavy reliance on multiple-choice examinations throughout the training continuum (in-training exams, board certification, fellowship selection, maintenance of certification) risks implying that medicine consists of discrete questions and answers. Oral examinations, which require trainees to reason aloud and defend decisions, assess epistemic sophistication in ways MCQs cannot. Expanding modalities that promote these traits across the continuum of education would signal that reasoning matters, potentially reshaping the study habits that have been distorted by pattern-matching test preparation. CBME frameworks should be explicitly reframed (if not renamed) so that competence is understood as the floor from which expertise is built, not the ceiling toward which training aims; this might include formal recognition pathways for trainees who pursue mastery beyond minimum thresholds. National organizations can champion curriculum reform focused on cognitive skills like decision-making under uncertainty. These organizations can also help develop assessment tools that measure clinical synthesis and diagnostic reasoning.

Conclusion

The specialty of anesthesiology has been transformed by decades of progress across multiple dimensions: patient safety, trainee wellbeing, institutional efficiency, cultural humanity, and educational standardization. These achievements reflect genuine values and should be protected.

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4 However, the conditions that cognitive science identifies as essential for adaptive expertise⁵ – the
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6 cognitive struggle that creates robust mental architecture, the time and continuity that enable
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8 reflection, deliberate practice with honest coaching, and the epistemic maturation that comes
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10 from navigating true uncertainty – have not been similarly protected. They have been
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12 systematically reduced, not through any single decision but through the cumulative effect of
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14 many reasonable ones.
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20 If we value clinicians who can not only follow protocols but adapt when protocols fail, who can
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22 not only use technology but function when it is unavailable, who can not only meet competency
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24 thresholds but exercise genuine clinical judgment under uncertainty, then we must design
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26 training systems that cultivate these capacities.
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31 This is not nostalgia for a harder past. The goal is not backward-looking restoration but forward-
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33 looking deliberate design. The pursuit of safety, wellbeing, efficiency, and expertise can coexist,
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35 but only if we recognize that each requires conscious design.
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Figure Legend

Figure 1. Unintended Consequences of Modernization on Expertise Development. The figure depicts a balance in which the collective weight of modernization advances (left) exerts downward pressure that cracks the foundation of adaptive clinical expertise (right). The cracking metaphor illustrates that these forces do not simply oppose expertise but fracture the conditions upon which it is built. The four lower panels detail specific mechanisms: safety and risk mitigation efforts may bypass the reasoning and autonomy required for clinical judgment; technology advances can shortcut deep cognitive processing and foundational skill development; system pressures prioritize throughput over mastery-oriented teaching; and cultural factors including work hour restrictions and emphasis on trainee comfort may limit the desirable difficulties that promote growth. Each force represents genuine progress; their combined effect on the learning environment requires deliberate countermeasures if adaptive expertise is to be preserved.

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Table 1: Threats to Expertise and Restorative Design Strategies. Threats to expertise development with corresponding deliberate restorative design strategies, organized by pillar of expertise development. Abbreviations: CBME, competency-based medical education; MCQ, multiple-choice question; MOC, maintenance of certification; OSCE, objective structured clinical examination.

Pillar	Threats to Expertise	Restorative Design
Cognitive Architecture	• Protocols and decision support that bypass clinical reasoning • Instant information access that reduces effortful encoding	• Require formulation of plans before consulting decision support • "What if" questioning during cases • Preoperative discussions for unhurried reasoning and learning needs detection
Reflective Practice	• Fragmented care from duty hours • Production pressure limiting debriefs • Feedback softening	• Prioritize case ownership and follow-through • Dedicated curricular reflection training and exercises • Strengthened longitudinal mentorship • Restore direct, honest feedback as norm • Value educational time in departmental metrics
Deliberate Practice	• Risk-averse supervision • Production pressure incentivizing takeover • Medicolegal concerns	• Recalibrate supervision to expect supported struggle • Treat trainee "comfort" as cue to practice an alternative • Create explicit opportunities for higher-stakes independence • Protect time for coaching and real-time feedback
Epistemic Development	• MCQ-dominant assessment and studying • Protocol-driven care implying "right answers" • CBME implying competence as goal • Time-variable training disincentivizing challenge-seeking	• Expand expository exams and OSCEs throughout training and MOC • Deliberate exposure to cases with conflicting guidelines • Faculty modeling: "I don't know, but here's how I'm thinking" • Explicitly frame CBME as floor, not ceiling • Reward reasoning under ambiguity in assessments

Advancements in anesthesiology training (safety, technology, culture) may unintentionally dismantle essential learning challenges, hindering the development of true adaptive clinical expertise.

