Title
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Journal
Academic Medicine, 98(9)

ISSN
1040-2446

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Publication Date
2023-09-01

DOI
10.1097/acm.0000000000005257

Peer reviewed

Fostering Adaptive Expertise Through Simulation

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Abstract

Technology-enhanced simulation has been used to tackle myriad challenges within health professions education. Recently, work has typically adopted a *mastery learning* orientation that emphasizes trainees' sequential mastery of increasingly complex material. Doing so has privileged a focus on performance and task completion, as captured by trainees' observable behaviors and actions. Designing simulation in these ways has provided important advances to education, clinical care, and patient safety, yet also placed constraints around how simulation-based activities were enacted and learning outcomes were measured. In tracing the contemporary manifestations of simulation in health professions education, this article highlights several unintended consequences of this performance orientation and draws from principles of *adaptive expertise* to suggest new directions. Instructional approaches grounded in adaptive expertise in other contexts suggest that uncertainty, struggle, invention, and even failure help learners to develop deeper conceptual understanding and learn innovative approaches to novel problems. Adaptive expertise provides a new lens for simulation designers to think intentionally around how idiosyncrasy, individuality, and inventiveness could be enacted as central design principles, providing learners with opportunities to practice and receive feedback around the kinds of complex problems they are likely to encounter in practice. Fostering the growth of adaptive expertise through simulation will require a fundamental reimagining of the design of simulation scenarios, embracing the power of uncertainty and ill-defined problem spaces, and focusing on the structure and pedagogical stance of debriefing. Such an approach may reveal untapped potential within health care simulation.

The origins of health care simulation are rooted in helping clinicians perform their work safely, with some of the earliest obstetric task trainers dating back to at least the 1700s. However, the confluence of several challenges facing health professions education in the early 21st century catapulted technology-enhanced simulation to the foreground as a logical and innovative educational approach.[1] Such challenges included concerns about patient safety, limitations on teaching time that resulted from the economic pressures of managed care organizations, and the development of new technological approaches, such as minimally invasive surgery.[1–3] These challenges, coupled with an increased emphasis on competency-based assessment for trainees,[4,5] necessitated training environments that could teach and assesses core skills safely and reliably.[1] Simulation was rightly viewed as a means by which trainees could practice patient care skills without exposing actual patients to harm. In fact, simulation was framed by some as an ethical imperative to address the safety concerns inherent in the status quo.[6] Fortuitously, important advances in simulation technology made such a shift possible. For example, full-scale mannikins and task trainers that were able to represent human physiology gradually became less expensive and more portable.[7,8]

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Acad Med. 2023;98:994–1001.
First published online April 21, 2023
doi: 10.1097/ACM.0000000000005257

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In addressing the emergent challenges at the turn of the century, simulation educators generally adopted a *mastery learning* model of education that emphasized trainees' sequential mastery of increasingly complex material.[9,10] Focusing on trainees' observable behaviors and abilities to complete tasks (e.g., performance orientation) in turn led educators to emphasize some affordances of the simulation context over others. These choices inherently limited the range of learning opportunities that simulation could support and potentially focused on outcomes or behaviors that were unintended.

Recent conversations about clinical competency have broadened to include *master adaptive learning* as a complementary perspective to traditional concepts of mastery.[11] Doing so presents the health care simulation community with a unique opportunity to reexamine its pedagogical underpinnings. In this article, we trace the origins of simulation's performance orientation, underscoring both its strengths and limitations, and use this historical orientation as a springboard to imagine an approach to health care simulation that places *adaptive expertise* as the central area of focus.

The Historical Origins of Simulation's Performance Orientation

The previously described challenges that were present within health care at the turn of the 21st century, coupled with concurrent calls for greater methodologic rigor in education studies,[1,12] led the foundational research of modern health care simulation to concern itself primarily with demonstrating its effectiveness compared with traditional modes of instruction.[13–15] The model of mastery learning was particularly well suited to this task and dovetailed nicely with programs' broader focus on competency-based education. Concepts germane to mastery learning informed the instructional design of training interventions, providing the scaffolding to both standardize expectations and measure learners' performance.[16–18] As a result, the simulation community worked toward creating technologies and models of teaching that would maximize the benefits of mastery-based learning techniques, such as *deliberate practice* whereby leaners honed their skills with intention and repetition, while creating environments where teachers could measure and strategically support learners' progress toward competency.[18] Many of these approaches emphasized the importance of clearly defined steps to perform tasks proficiently and efficiently and stepwise designs that provided mechanisms for both procedural instruction and the optimization of performance on patient care algorithms, such as Advanced Cardiac Life Support.[19,20]

More recently, educators have explored affordances of simulation beyond procedural training, such as its utility for honing the skills of leadership and teamwork in resuscitation. However, these opportunities, too, have incorporated a mastery learning approach and therefore have been developed with the underlying premise that performance can be maximized through algorithmic approaches that can be taught, enacted, and measured. For example, highly structured frameworks, such as Crisis Resource Management, have been invoked to describe how teams can function effectively in high-stakes and time-dependent situations, with assessment instruments that enumerate each detailed step of an optimal performance.[21–23] Numerous performance-oriented strategies for debriefing have been developed as well, structured around techniques to support learners' understanding and using predefined best practices as means to identify and remediate areas of suboptimal performance.[24–26] In these ways, simulation has organized itself around design principles that optimize demonstrably replicable practices by both individuals and teams.

The successes attributable to these performance-oriented approaches have been substantial. For example, simulation-based training has decreased complications from central venous catheter insertion,[27] improved the acquisition and transfer of surgical skills from the simulation laboratory to the operating room,[16,28,29] and improved the performance of resuscitation teams responding to in-hospital medical crises.[19,20,30] The simulation community's orientation toward mastery and emphasis on performance-oriented teaching have demonstrably helped practitioners to deliver health care more safely and efficiently.

However, the goal of performance mastery has had consequences for the ways in which teaching, learning, and assessment take place in simulated learning settings. By aiming to create scenarios in which learners' performance can be reliably invoked and measured, educators have largely relied on case vignettes with well-defined clinical content that is framed by prespecified learning objectives and critical actions.[31–33] Such tightly scripted scenarios are a limited approximation of how these skills or behaviors actually play out in authentic clinical practice. Similarly, simulation educators have placed a heavy emphasis on the use of *debriefing*, an interactive dialogue between educator and learner that is intended to clarify the learner's understanding of the simulation experience as well as reflect on their performance.[34] However, although several approaches to debriefing have been developed,[24,25,35,36] they share a common orientation toward identifying and exploring *performance* gaps at the conclusion of the simulated experience.[22,33] When "in scenario" debriefing techniques (such as rapid-cycle deliberate practice and microdebriefing) have been described,[26,37,38] most are intended to remediate incorrect actions or function as brief coaching interactions aimed at helping learners navigate expected courses of management. Thus, although simulation is rightly considered to be a form of *experiential* learning,[39–43] current design principles focus on predictable, observable, and measurable behaviors. This approach creates highly curated experiences for learners that may limit the ways in which learning moments are explored and understood by teachers and learners alike.

In the next sections, we explore the ways in which commonly encountered challenges in the instructional design of simulations illustrate important gaps between simulated and authentic clinical practice. We then theorize an approach to simulation that places adaptive expertise at its center, exploring the theoretical implications for the instructional design of simulations and approaches to debriefing.

Hiding in the Shadows: What Simulation's Current Orientation Might Miss

Simulation experiences are intended to mimic situations and challenges that clinicians face in practice. This effort at creating real-world *fidelity* is intended to foster engagement and provide learners with a sense that what they do in simulated learning environments has direct relevance to the workplace. However, familiar tensions arise for educators as they attempt to create these types of real-world experiences in the simulation environment. For example, when learners deviate from the intended diagnostic or management experiences of a simulation, an instructor is left scrambling to modify the scenario or intervene in ways that bring learners back to the expected course. If learners seek diagnostic approaches or resources that a scenario cannot support (e.g., point-of-care ultrasonography), the instructor is forced to change the rules of the game (e.g., "You don't have that available right now.") or ask participants to further suspend their disbelief (e.g., "You've performed the bedside ultrasound and it shows no intra-abdominal free fluid."). As learners become well practiced at simulation, they may use clues that they would not in real life (e.g., "I know my instructor is a toxicologist, so this is probably a toxicology-related case.").[44] Perhaps most importantly, scenarios are often built with supporting data that focus on a clear diagnosis or management approach, creating the false impression that authentic clinical management is more an act of puzzle solving than problem definition or sensemaking.[45,46] Thus, if supporting stimuli are ambiguous, learners may feel defeated (or worse, cheated) by the scenario and leave these experiences without the clear take-home learning points they expected. A skillfully led debrief may help learners fill in these blanks, but it will do so without the benefit of them having explored how they managed their experiences of uncertainty in the moment.

In part, these struggles arise because authentic clinical medicine rarely presents clearly defined puzzles. Instead, clinical medicine is rife with uncertainty.[47,48] True clinical problems are often *ill-defined*, characterized by "conflicting assumptions, evidence, and opinion which may lead to different solutions."[47(p223)] Such ill-defined problems require clinicians to use skills beyond those necessary for routine practice. They also require clinicians to identify and characterize the emerging situation moment by moment, continuously gauge the impressions of others around them, and negotiate their way forward despite ongoing uncertainties.[49] Managing these types of complexities in practice requires clinicians to become *adaptive experts*, effective in routine situations and also sufficiently flexible and innovative when responding to the uncertainty, complexity, and idiosyncrasies of novel situations.[50,51] Adaptive experts possess conceptual knowledge of both *why* and *how* things work,[52] using analogical problem solving and creativity to transfer skills to unfamiliar situations.[52] Doing so requires clinicians to reflect on their practice, to use meta-reasoning skills to identify instances when routine schema will not work, and to adopt critical thinking that challenges assumptions and beliefs.[11]

Adaptive expertise also involves what Schön termed "reflection-in-action," meta-cognitive approaches that enable clinicians to "reshape what we are doing while we are doing it."[53(p26)] Cristancho et al conceptualized these types of reflections as a continuous *reconciliation cycle*, a process "of gaining and transforming information through comparison to what is expected or typical and/or against the planned course of action – to obtain a new meaning that is useful for solving the situation."[54(p66)] Moulton et al[55] described this awareness of potential dangers in the operative setting as "slowing down when you should" and highlighted the ways in which the heightened awareness and deliberate thinking associated with slowing down enabled surgeons to move through complex operative problems. Ilgen et al[49] characterized reflection on action as holistic appraisals of comfort (or discomfort) that are informed by cognitive, somatic, and emotional cues that physicians notice as they move through experiences of uncertainty. Clinicians' degree of comfort in this model is informed by their efforts to both "forward plan"[55] (e.g., imagine what might happen to a patient as a problem evolves or a management approach is enacted) and concurrently monitor their patients, their environments, and themselves as a situation unfolds.[49,56,57] The cyclical interplay between planning and monitoring gives clinicians a real-time sense of whether they are on track (even if a problem remains ill-defined), what to look for as a problem evolves, and when to ask others for help.

Importantly, an adaptive expertise mindset is neither the exclusive domain of experienced practitioners nor the inevitable consequence of experience; rather, the skills of adaptive expertise must be fostered and reinforced intentionally throughout training.[58] Thus, if a goal of simulation is to help learners accurately apprehend, shape, and manage problems as they would in real life, simulation must have a means of supporting the types of skills that enable expert clinicians to safely and confidently navigate the types of ill-defined problems they are likely to encounter in practice.[49,59] Given the emphasis that existing simulation-based instructional paradigms place on standardization and replicability, a shift toward experiences that foster adaptive expertise could offer a new direction for programs aiming to develop the skills, cognitive states, and behaviors of adaptive experts in practice.

Simulation Reconsidered: Supporting Adaptive Expertise

Clinical reasoning is highly content and context dependent.[60] Thus, it is likely that clinicians will experience and understand ill-defined problems in idiosyncratic ways based on their past training and patient experiences. Simulation scenarios geared toward prototypical presentations and clear-cut diagnoses miss opportunities for appropriately advanced learners to experience tensions, such as how their own abilities and experiences are aligned (or misaligned) with the unique problem(s) at hand or how different clinicians might (appropriately) manage the same situation differently.[61] As a result, much of the beneficial cognitive work of navigating uncertainty and clinical ambiguity may be lost. Said differently, existing approaches emphasizing the fidelity of the mannikin, clinical environment, or clinical tools provide *structural* fidelity (i.e., physical realism) to the experience. Even so, scenarios may lack fidelity in the idiosyncratic ways that ill-defined problems manifest and are managed by different clinicians in authentic clinical practice. We would call this quandary a lack of *epistemic* fidelity, namely a failure to capture the complexity of authentic clinical problems. We would suggest that no matter how lifelike the scenario is in its structural fidelity, without epistemic fidelity the scenario will lack realism for the learners who have seen real problems play out in workplace settings. It was this concern that led Bligh and Bleakley to posit that much of current simulation training functions more as a "simulacrum"[62(p606)] (an unsatisfactory imitation or substitute), which they suggested leads to a simulation of learning rather than to effective learning by simulation.

Adaptive expertise can provide a new lens for simulation designers to think intentionally around how idiosyncrasy, individuality, and inventiveness could be enacted as central design principles in simulation to give learners more practice and feedback around managing ill-defined problems. Instructional approaches that have been used to foster adaptive expertise in other contexts suggest that uncertainty, struggle, invention, and even failure are crucial for learners to develop conceptual understanding of how to make sense of ill-defined problems and provide a foundation for exploring new approaches.[51] However, opportunities for struggle must be combined with principles of cognitive integration to help learners develop coherent mental models and rich conceptual knowledge that form the basis of adaptive expertise.[51] This speaks not only to the role of instructional design but also to the nature of the instruction. Thus, such a shift might include *guided discovery*, in which "the student receives problems to solve but the teacher also provides hints, direction, coaching, feedback, and/or modeling to keep the student on track."[63(p15)] This approach would involve the use of more authentically open problem spaces and educational approaches, such as teacher-guided reflective inquiry.[52] Such approaches, in combination, create challenges that allow learners to be effectively supported while they engage in *productive struggle*, a learning process that focuses on hypothesis development and problem solving.[64,65] In doing so, the goals of these exercises shift toward developing an understanding about when to use a procedure or approach—and how to adapt it effectively to the current situation—rather than merely emphasizing how to perform a procedure correctly.[51,52] Bringing these ideas together, simulation could support the development of adaptive expertise through exercises that enable learning through challenging experiences, strengthen an individual's ability to self-reflect, and highlight their interdependence with others. These key instructional elements are explored in greater detail below.

Embracing the power of uncertainty and productive failure

Traditional approaches to simulation and debriefing have done much in terms of creating safe spaces for failure, allowing learners to practice invasive procedures and train for high-risk and low-frequency events while protecting actual patients.[1,6,14–20] However, the development of adaptive expertise requires educational supports and approaches that differ in important ways from the traditional pedagogical approaches favored by simulation. For example, meta-cognitive instruction, guided discovery with hypothesis testing, problem solving, and productive failure are all seen as key design features for fostering adaptive expertise.[51,52,64] Problems that initially hinder performance may actually *facilitate* learning (hence the concept of desirable difficulty).[65] In addition, productive failure, which combines the opportunity to struggle with expert guidance, is the instructional design most strongly associated with learning.[65]

Simulation affords multiple opportunities to enact the key design features of productive failure: a problem-solving task challenging enough to engage the learner in exploration but not so challenging that the learner gives up; the allowance of multiple solutions or strategies, with the space to explore; the activation of both formal and intuitive prior knowledge; and the presence of a teacher or an expert to build on student-generated solutions.[65] By combining exploration and struggle with opportunities for instruction and knowledge consolidation, productive failure sets the conditions for *preparation for future learning*.[65] Preparation for future learning is "the ability to learn new information, make effective use of resources, and invent new procedures to support learning and problem solving in practice."[64(p116)] Preparation for future learning is heavily related to adaptive expertise and involves training people to be open to engaging with and learning from ill-defined problems (i.e., learning how to learn in novel contexts). A central concept within preparation for future learning is the idea that learning is the process of not only accruing new information but also learning how to organize and reorganize prior knowledge. By combining productive struggle and guided discovery with scenarios that address uncertainty as a central focus, simulation may help learners capitalize on opportunities for safe innovation rather than simply providing a setting for safe failure.

Leveraging and supporting self-regulated learning and socially shared regulation of learning

Self-regulated learning (SRL) has been defined classically as "self-generated thoughts, feelings and actions that are planned and cyclically adapted to the attainment of personal goals."[66(p72)] SRL is a cyclical process and is typically characterized by 3 sequential phases: forethought (processes preceding action), performance (processes during action), and self-reflection (processes following action).[67] Prior research has demonstrated that learners' use of SRL strategies can be made explicit through simulation, specifically through techniques such as SRL microanalytic assessment, which involves giving learners feedback about their strategic processes, regulatory processes, and motivational processes while they are performing a clinical task.[68] Thus, rather than relying solely on post hoc debriefing, simulation might embrace approaches that engage learners' SRL in real time.

Self-regulation is a key component of adaptive expertise, and there are many opportunities to foster self-regulation in simulated settings. This is particularly true when experiences can be uncoupled from content-driven learning objectives and critical actions that map to a prespecified diagnosis. Thus, experiences aiming to foster adaptive expertise would focus on real-time explorations of ill-defined clinical problems, creating opportunities for learners to articulate what they are experiencing (cognitively, emotionally, and somatically) during moments of uncertainty and thinking deliberately how they might safely move forward.[69] Simulations could be built with the flexibility for learners to consider and practice different diagnostic and management approaches, weigh them against each other, and reflect on the different ways that these experiences played out. In addition, instructors could facilitate scenarios in ways that mimic how more novice learners *actually* practice in supervised clinical settings, engaging in cognitive tasks (such as cross-checking their understanding against that of their instructor) that more accurately reflect the ways in which they maintain safety while learning and navigating uncertainties in practice.[70,71]

Reimagining simulation as a space to explore ill-defined problems for which there is no single right answer levels the playing field for learners and instructors. Through guided discovery, the instructor provides an experienced perspective rather than holding absolute knowledge. Rather than using postevent debriefing as a means of comparing observed performance to a prespecified ideal framed by learning objectives and critical actions, this approach shifts emphasis to a learner-driven process of clarifying understanding, comparing approaches, and identifying areas for continued learning. Shariff et al[72] described how simulation can support ongoing SRL after a simulation activity has concluded, contrasting the dominant practices of simulation that frame successful transfer in terms of short-term knowledge retention and direct application toward using simulation to challenge learners to identify complex learning goals that require further work. By placing explicit emphasis on the tools of SRL and adaptivity within scenarios as well as postscenario debriefings, we believe that we can further extend simulation's reach in shaping learning that more closely reflects what arises from experiences with complex problems in the workplace. Such approaches align nicely with current conceptualizations of coregulated learning, whereby learners' cognitive and meta-cognitive activities are influenced or mediated by professionals with greater expertise, experience, or authority.[73,74]

Simulation also affords unique opportunities to explore how groups of clinicians work through ill-defined problems together. In contrast to existing models that frame teamwork around methods of communication and leadership, a shift toward focusing on the negotiations that take place among individuals as they struggle to make sense of and manage ill-defined problems offers new ways of thinking about how adaptive expertise might manifest in shared work settings. Socially shared regulation of learning offers one lens to unpack these complex phenomena, focusing on "processes through which team members share the regulation of their collective learning activities, directed towards the pursuit of their jointly constructed goals."[74(p31)] In contrast to coregulated learning, which assumes that individuals with greater authority or influence will regulate the activities of others, socially shared regulation of learning assumes a more evenly distributed and reciprocal construction of expertise and influence among group members.[73,74] Simulation activities that are intentionally structured with groups of learners could provide a rich setting for idea generation, group reflections, and proposed courses of action that can enable teams to better understand how they can learn from each other as they collectively negotiate complex problems.

Implications

The key to unlocking the latent potential within simulation to support adaptive expertise may lie in embracing its technology-independent affordances. Although the future development of simulation technologies can and should incorporate the perspectives of both developers and experts in educational design, we hold the position that advancing pedagogy in support of adaptive expertise through simulation is not dependent on technological advancement per se. Rather, it is through simulation's affordances of starting and stopping time, providing opportunities to describe one's thought process as it unfolds, and allowing learners to seek and rehearse new approaches and solutions that we may better examine and support the developing cognitive processes of learners. However, such a philosophical reorientation of the purpose and format of simulation brings with it a number of additional issues and questions that bear consideration. Among these are a corresponding adjustment to the design of simulation cases and the role of debriefing.

First, we might imagine a very different structure for the problems that learners face in simulations. As described earlier, existing simulation practices have provided great advances in how clinicians work through *routine* problems and practices, but much of clinical expertise involves judgment when managing unknowns rather than optimizing one's efficiency at managing problems for which no best answer or approach is evident. As an example of how such uncertainty might manifest in the simulation context, Martin Pusic, MD, PhD (Boston Children's Hospital/Harvard Medical School, written communication, September 7, 2022), described a simulation exercise involving the management of a critically ill child with diabetic ketoacidosis and altered mental status. In addition to managing the child's diabetic ketoacidosis, the learner must weigh the potential positive and negative consequences of intubation (the advantages of ensuring airway protection and oxygenation against the potential of worsening acidosis and cardiovascular collapse). Whereas a traditional simulation case might emphasize correct diagnosis of diabetic ketoacidosis and knowledge of its protocolized care, this case introduces irresolvable tensions in clinical management. Cases such as this move beyond correct diagnosis and treatment, challenging learners to wrestle with decision making when no right answers exist.

Second, shifting the nature of the problem space with which learners are faced also enables a repositioning of the role of the instructor in the simulation. Although much has been made of the stance of the instructor as a colearner who is seeking to clarify and understand the perspective of trainees,[25,35] an inherent asymmetry exists within this relationship. It is the instructor who, in addition to domain-relevant experience and expertise, holds the insider's knowledge of the learning objectives (which may or may not have been made clear to the learner) and structure of the simulation. As Ng et al[75] have pointed out, the idea that simulation offers a "safe space" where learners can explore new concepts and material without judgment may be at odds with values that permeate medical culture (such as deference to hierarchy), which this asymmetry reinforces. Whereas traditional simulation approaches place the instructor in an elevated position in relation to the learner, reimagining simulation as a space to explore ill-defined problems for which there is no single right answer might level the playing field. Rather than providing definitive answers to known problems (e.g., "This patient had an aortic dissection, the management for which consists of…"), the instructor might instead be prompted to reveal their own thought process when wrestling with uncertainty (e.g., "I have had tough cases like this, and I'm going to share with you a couple of strategies that have helped me as I struggled to untangle what was going on."). In this context, the instructor assumes a position of providing an experienced perspective rather than holding absolute knowledge.

Third, shifting the problem space and the role of the instructor allows for consideration of the role of debriefing and feedback. Debriefing and feedback are viewed as the most important elements of simulation[1,24,25] and fall largely within the purview of the instructor facilitating the activity. In a critical review on the topic, Sawyer et al stated that "feedback is viewed as the one-way conveyance of information to the learner. In contrast, debriefing is defined as an interactive, bidirectional, and reflective discussion or conversation."[25(p209)] Numerous postevent and within-event debriefing approaches have been described, yet whether occurring within or after the simulation activity, these approaches share a common focus on a set of prespecified learning objectives as a substrate for debriefing.[25] Rather than using postevent debriefing as a means for comparing observed performance with a prespecified ideal framed by learning objectives and critical actions, a focus on developing adaptive expertise in simulation might shift emphasis to a learner-driven process of clarifying understanding, comparing approaches, and identifying areas for continued learning. For example, a postsimulation debriefing might center around learners identifying moments of uncertainty or unease during a scenario, using dialogue with their instructors to surface strategies of self-monitoring and planning (e.g., "It made me nervous when I saw his oxygen saturation drop, and made me start thinking about where to find the intubation equipment…"), monitor others' behavior (e.g., "I had a sense from your body language that you were seeing something different than I was…"), or make efforts to contextualize past experiences as they wade through complex and evolving problems (e.g., "I've always seen it done this way, but wasn't sure if that would work here…"). If we were to combine cases that pose authentically complex clinical dilemmas such as these with instructional designs that encourage learners and instructors to engage in running dialogues, we might create conditions that would truly support learners' reflection in action and skills of self-regulation.[53,67–69] Such approaches, which may involve strategies such as starting and stopping the scenario to weigh management decisions, clarify understanding, or try different approaches sequentially, align closely with what Cianciolo and Regehr[76] have termed "feedback-in-practice" and approximate the ways that teachers and learners interact in the course of real clinical cases.

Conclusions

We have used the lens of adaptive expertise to highlight ways in which instructional design practices might reinforce skills germane to navigating ill-defined problems in practice. To this end, we propose a shift toward greater epistemic fidelity in simulation practices, shifting from outcome-based orientations that emphasize *doing things right* (based on a prescriptive, decontextualized reference to procedural standards) to process-based orientations embodied by master adaptive learners that emphasize *doing the right things* (making considered choices and adapting effectively to the conditions).

This shift raises several important questions for educators and researchers. For example, how does one strike a balance between providing the necessary scaffolding around routine problems and procedures and the more complex and idiosyncratic problems that learners are likely to see in practice? What is the right balance between simulating routine protocols that build a learner's *sense of competence* with challenges that are more likely to make them *authentically competent* with adaptive skills that enable them to struggle productively, respond innovatively to new changes, and foster effective interdependence with others? Finally, perhaps most importantly, at what stage in a learner's development is it appropriate to remove the scaffolding that shapes routine practice and begin to explore adaptivity without causing undue confusion or angst?

Additionally, a focus on understanding the ways that self-regulated and socially regulated learning takes place in simulated environments offers many opportunities for future study. To do so requires a better understanding of the ways in which psychological safety may influence how learners are willing to share with others, the ways in which noncognitive contributions (e.g., emotions, somatic states) influence their experiences with ill-defined problems, and the ways in which interdependence and collective competence are fostered in real time.[77–82]

Despite simulation's long list of successes, we believe it holds still greater potential with respect to fostering adaptive expertise. The keys to unlocking this potential may lie in affordances of simulation that are independent of technology and that can be accessed through aspects of instructional design that have largely been overlooked. The literature describing uncertainty and ill-defined problems, self-regulated and socially shared regulation of learning, and the design techniques of productive failure and guided discovery point to fertile ground for new approaches to simulation.

Acknowledgments: The authors would like to gratefully acknowledge Martin Pusic, MD, PhD, and Sandrijn van Schaik, MD, PhD, for their thoughtful contributions to the manuscript.

Funding/Support: None reported.

Other disclosures: None reported.

Ethical approval: Reported as not applicable.

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