Acquisition and Maintenance of Medical Expertise: A Perspective From the Expert-Performance Approach With Deliberate Practice

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Abstract

As a part of a special collection in this issue of *Academic Medicine*, which is focused on mastery learning in medical education, this Perspective describes how the expert-performance approach with deliberate practice is consistent with many characteristics of mastery learning. Importantly, this Perspective also explains how the expert-performance approach provides a very different perspective on the acquisition of skill. Whereas traditional education with mastery learning focuses on having students attain an adequate level of performance that is based on goals set by the existing curricula, the expert-performance approach takes an empirical approach and first identifies the final goal of training—namely, reproducibly superior objective performance (superior patient outcomes) for individuals in particular medical specialties. Analyzing this superior complex performance reveals three types of mental representations that permit expert performers to plan, execute, and monitor their own performance. By reviewing research on medical performance and education, the author describes evidence for these representations and their development within the expert-performance framework. He uses the research to generate suggestions for improved training of medical students and professionals. Two strategies—designing learning environments with libraries of cases and creating opportunities for individualized teacher-guided training—should enable motivated individuals to acquire a full set of refined mental representations. Providing the right resources to support the expert-performance approach will allow such individuals to become self-regulated learners—that is, members of the medical community who have the tools to improve their own and their team members' performances throughout their entire professional careers.

The main goal of this Perspective is to describe the expert-performance approach and explain how it provides conceptual context for deliberate practice. I demonstrate how this approach is consistent with many aspects of attaining mastery in medicine, but also how it differs in some regards from the traditional mastery learning emphasis in medical education. In addition, I describe some exciting developments related to expert performance and deliberate practice that have occurred in medicine since 2004 when the original article on that topic was published in this journal.[1] I discuss how the expert-performance approach and the concept of deliberate practice have been successfully applied in a few areas of medicine, and I suggest possibilities for future research. I begin with a short review of the expert-performance approach, drawing mostly on examples from piano and violin, chess, and sports. Next, I describe, still considering evidence from other fields, the longitudinal development of expert performance with an emphasis on the acquisition and refinement of the complex cognitive mechanisms that would also mediate superior reproducible performance in medicine.

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The Expert-Performance Approach

The expert-performance approach proposes that it is necessary to identify reproducibly superior performance in the real world, and then to capture and reproduce this performance, ideally with standardized tasks for examination, in the laboratory.[2,3] In domains with competitions—such as music, ballet, sports, and chess—identifying individuals whose performances are reproducibly superior is relatively simple.[4] In contrast, it is much more difficult to measure expertise when it involves the training and/or treatment of humans—such as in K–12 education, psychotherapy, and surgery. Identifying objective measures of reproducibly superior performance for individuals in these domains is challenging.

Objective performance in these domains can be measured by the outcomes of treatments in everyday life, but collecting and analyzing the necessary *amount* of outcome data is difficult. To illustrate, in education, measuring students' performance on standardized tests before any given teacher is assigned to a specific class of students (pretest) and then testing the same students at the end of the year, using similar standardized tests (posttest), enables the calculation of the students' improvement (the added value induced by their teacher). The average improvement of all the students of a given teacher can then be computed and compared with the improvement induced by other teachers with similar assignments in order to provide an objective measure of each teacher's relative performance.[5] Similarly, measuring the performance of psychotherapists based on the difference of pre- and postrating by treated patients is possible.[6,7] In some domains of medicine, such as breast reconstructions[8] and hand surgery,[9] patient satisfaction ratings of outcomes serve as the most important measures to assess the success of medical treatments. (Recently, however, several reports have shown that patient satisfaction ratings do not correlate with objective outcomes of surgery or surgical procedures[10]—perhaps because the patients were anesthetized,[11] unable to judge the quality of procedures [e.g., as in the case of colonoscopy[12]], and/or unable to predict long-term outcomes of the treatments.) The expert-performance approach requires reliable, objective, long-term outcomes. In surgery, such outcomes may be reduced reoccurrence of cancers.[13,14] Understanding the individual differences among professionals' performance requires the calculation of average outcomes for many hundreds of hours of teaching, psychotherapy, and surgery. The associated massive amounts of behavioral interactions make it very difficult to identify differences in specific behaviors or actions that might account for the observed individual differences in average performance.

As mentioned, identifying experts with consistently superior outcomes is simpler in some domains (chess, music, sports). One of the most extensively researched domains of expertise is chess. A chess player's skill level is determined by his or her wins and losses at chess tournaments; outcomes from some 20 to 40 matches against opponents with different chess ratings are necessary to compute an accurate chess rating for a single individual.[15] To complete that number of chess matches takes over 100 hours of chess playing or over 1,000 chess moves. All chess moves are not equally important for outcomes of chess games; thus, some moves will not differentiate chess players with different skill levels. In fact, evidence shows that only a small number of critical moves per game will clearly distinguish superior players from those with lower chess ratings, offering a great opportunity for the study of the development of expertise. In a pioneering study, De Groot[16] identified several critical chess positions taken from real games and asked world-class players and members of local amateur chess clubs to think aloud while they picked the best move for each position without any imposed time limit. The world-class players picked the best move after exploring the chess position extensively—from half a minute to around 20 minutes, whereas the club players did not even consider the best move during their extended deliberation. Subsequent researchers have applied de Groot's findings, extracting critical chess positions from games between chess masters and instructing other chess players to try to select the best move for these positions. Players, be they novices or grandmasters, are able to provide selections for a position within 30 seconds, and for about two dozen positions within 15 to 20 minutes, producing a total score that is highly correlated (r around 0.8) with their official chess rating.[17]

At a glance, this type of test might seem similar to patient management scenarios in medicine that allow open-ended answers,[18] but the chess positions are exact duplicates from actual chess games, whereas the key-features problems for managing patients are *constructed* by experienced medical doctors. The correct answers for the key-features problems are validated by experienced medical doctors through *consensus*, whereas the correct chess moves are determined by world-class chess players and more recently by computer programs, which are vastly superior to human players in their move selection.[19] Finally and most important, the case-management scenarios in medicine are designed to test medical students' and personnel's minimal competencies,[18] whereas the move-selection tests are predictive of real-world performance across the whole spectrum of chess skill from regional to international level.[17] Medicine requires tests, similar to those developed for chess, to measure performance that are highly correlated with the real-world outcomes of actual patients.

The accurate measurement of reproducible performance in a domain provides an opportunity to identify aspects of the performance that can be improved. When chess players analyze a completed chess match and realize that they have selected an inferior move, they have the opportunity to improve their future performance. By attempting to select moves for a large number of chess positions with known best moves, chess players can identify occasions when their initial selections led to inferior moves. With the knowledge of the better or even best move, players can work on changing the cognitive processes that mediate the generation and selection of moves so that, in the future, they can select the superior move and improve their overall game. In previous research,[20] colleagues and I proposed that this type of solitary study, using a library of chess positions with best moves, can provide an environment for effective learning and improvement of chess performance.

When this type of training is supervised and guided by a teacher, it is called "deliberate practice"—a concept my colleagues and I introduced in 1993.[20] We defined deliberate practice as "the individualized training activities specially designed by a coach or teacher to improve specific aspects of an individual's performance through repetition and successive refinement,"[21(pp278–279)] and we clarified that, "To receive maximal benefit from feedback, individuals have to monitor their training with full concentration, which is effortful and limits the duration of daily training."[21(p279)]

To test for the effects of deliberate practice, we collected data on the development of violin students all attending the same prestigious international music academy.[20] Using teacher-generated ratings, we were able to identify three groups of violinists who differed in performance. We compared data on the development of those who had the potential to become international soloists with data on the development of two groups of less accomplished violinists in order to identify training and practice activities that might have contributed to the first group's development of superior performance. Violinists in all three groups indicated that the time they spent practicing alone, on tasks with goals determined at weekly meetings with their teachers (i.e., in deliberate practice), was the primary relevant activity for improving their performance. The violinists estimated the average number of hours per week they had engaged in this deliberate practice alone each year over their entire development as musicians, and we validated their estimates of their current level of practice by collecting a weeklong diary. This research showed that even at this elite level of performance, the amount of solitary practice accounted for significant differences among the groups: The more highly accomplished violinists had accumulated more practice than the other two groups.[20] This finding contradicted the view, common, at least at the time of the study, that among the highest levels of performers, innate talent was the only determining factor.

Development of Expert Performance as a Sequence of States With Three Types of Representations

The expert-performance approach assumes that an individual's performance in a domain develops gradually—starting with an initial level of performance that improves sufficiently to eventually permit participation in activities in the domain. Subsequent performance progresses slowly to higher levels, including expert levels. According to this assumption, it should be possible, at least in principle, to describe the development of each individual's performance as an ordered sequence of stable states of performance (see Figure 1). Each state can be described in terms of three types of representations and their interconnections. These three different representations can be easily identified in expert musicians (Figure 2). The first type of mental representation allows expert musicians to image the particular sounds that they want to attain while playing a piece—that is, in preparing for a public concert, expert musicians will image what a piece of music will eventually sound like when they perform it for an audience (see Representation 1 in Figure 2). This same representation (Representation 1) allows musicians to form an image of the desired sound of a part of the piece *before* they play it. The second representation (Representation 2 in Figure 2) attempts to translate the image in the first representation into actions which result in music that anyone listening to the musician's performance can hear. The third and final representation (Representation 3 in Figure 2) permits expert musicians to listen to what their current performance sounds like as they are playing. Any discrepancy between the aspired expression of music (Representation 1) and the actual expression of music (Representation 3) allows expert musicians, first, to identify differences, which they can reduce by focused practice, and then, eventually to produce an approximate realization of the aspired expression.

The observable changes in the attainable performance, as well as the associated changes in the structure of the representations, as illustrated, respectively, in Figures 1 and 2, need to be described for each domain of expert performance. The detailed cognitive processes and practice activities will, of course, differ across domains of expertise (e.g., chess, music, sports, teaching, surgery), but the general principle remains: Performers aspiring to expert levels must engage in training activities that are not only designed to improve particular aspects of performance but are also integrated with all the other aspects of performance. When aspiring experts have improved and mastered one aspect of performance, they must then direct their attention to other improvable aspects.

My colleagues and I proposed a framework for explaining or illustrating the development of expert performance in music.[20] Consistent with the findings of Bloom,[22] our framework includes the *start* of playing an instrument. We explicitly identify the initial playing of an instrument because playing an instrument is nearly always linked to, at least in the beginning, instruction by a parent or professional teacher.[20] Producing enjoyable music without any prior training is difficult, whereas even a child can learn to kick a ball by trial and error without any instruction. The duration of focused practice for children learning an instrument is recommended to be relatively short, around 10 to 20 minutes per day, allowing the child to engage in play outside of practice. During the beginning phases of regular practice, parents help the children to detect errors and make corrections and, thus, improve their performance. Eventually the aspiring musicians will acquire their own mental representations that permit them to hear the sounds of their own playing and detect any problems by themselves.[2] Initially, however, the majority of young musicians lack the ability to hear the sounds of their own music. Without an instructor to help them identify and correct problems, beginners end up just playing the same mistakes over and over, as shown by studies analyzing videotaped practice sessions.[23] Additionally, the ability to listen to the music that one produces is critical for the motivation to keep striving to improve. Music students who can hear or image representations of how the

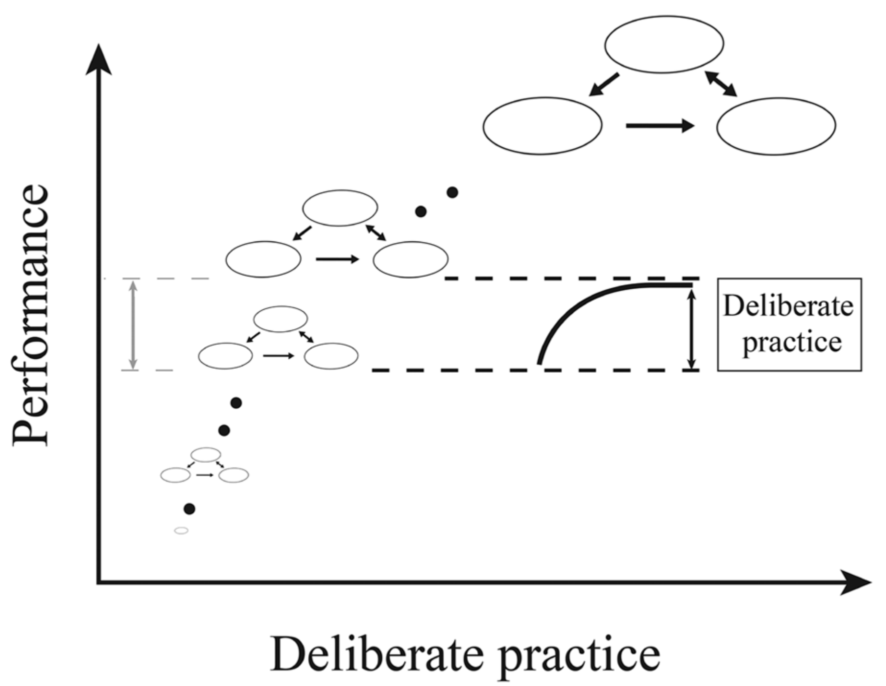

Figure 1 A schematic illustration of the acquisition of expert performance as a series of states with mechanisms of increasing complexity for monitoring and guiding future improvements of specific aspects of performance. Each state can be described in terms of three types of representations and their interconnections (see Figures 2 and 3), where the increased size of the ovals illustrates the corresponding representation's increased complexity, refinement, and interconnectedness. (Adapted from Ericsson KA. The scientific study of expert levels of performance can guide training for producing superior achievement in creative domains. In: Proceedings From the International Conference on the Cultivation and Education of Creativity and Innovation. Beijing, China: Chinese Academy of Sciences; 2009:14.)

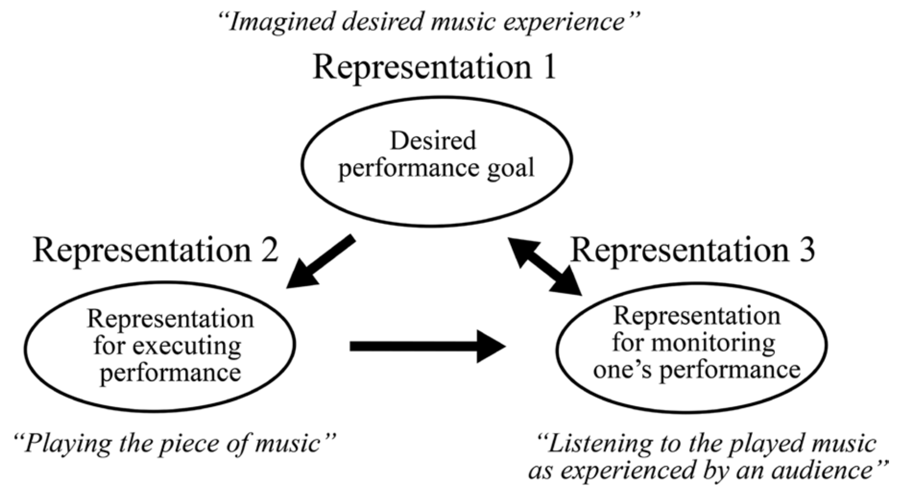

Figure 2 Three types of internal representations that mediate expert music performance and its continued improvement during practice. (Adapted from Figure 6, Ericsson KA. The scientific study of expert levels of performance: General implications for optimal learning and creativity. High Ability Stud. 1998;9:92.)

music is supposed to sound often enjoy hearing themselves play their favorite pieces, and they experience joy when producing new sounds associated with increasingly complex music pieces.

To summarize, deliberate practice[20] (see middle part of Figure 1) occurs when advanced students (such as those at an internationally acclaimed music school) follow their teachers' recommendations for practice activities (training tasks)—assuming, that is, that the students practice with full concentration toward the current practice objectives (training goals); that the students receive or self-generate immediate feedback; and that the training tasks offer opportunities to make repetitions with gradual improvements (structure of practice).

Several articles[2,24–28] have described the particular forms of teacher-guided practice (deliberate practice) in domains other than music. Importantly, an excellent teacher in any domain helps his or her students develop their own mental representations such that the students can eventually take on most of the teacher roles, evaluating their own performance and even, eventually, designing their own practice goals and being able to increasingly image, monitor, and refine their own performance.

Expert performers will continue for decades in their professional domains after they have completed their training and education. Less research covers this phase, when performers transition to other roles (teacher, coach, manager, judge) within the domain of expertise. In the domain of music, it is relatively common for older musicians to perform professionally in public, which allows the audience and music critics to directly compare their performances with those of their students and/or younger musicians. When my colleague and I[29] compared expert pianists ranging in age from 50 to 70 years old with young expert pianists in their 20s, we found two interesting results. Using laboratory tasks designed for research on aging (e.g., speeded choices, speeded substitution of digits for letters), the older experts performed much worse than the young experts and matched the performance of a group of amateur pianists matched for age.[29] Most interestingly, when we tested all young and old pianists on musically relevant tasks, we again observed a reduction in performance among the older expert pianists; we found that, for some older pianists, this decrement was associated with stopped or at least reduced engagement in weekly practice. The age differences were no longer significant when we controlled (statistically) for the amount of maintained practice (weekly hours of practice alone).[29]

More generally, a review of performance shows that skill in activities, such as typing and flying airplanes, decays as a function of the length of time since the cessation of practice.[30] Evidence from one recent study shows that taking a break from solving crosswords for a year or more reduces a puzzler's performance in crossword competitions.[31] Also, a large body of evidence from sports shows that reductions in the intensity of practice, as well as complete cessation of training, lead to decreased physiological adaptations and decrements in sports performance.[32] The high level of performance attained by master athletes over the age of 60 and even 70 who, importantly, engage in high levels of practice weekly is remarkable.[33] Collectively, these findings imply that continued practice during one's life is very important for maintaining a high level of performance, and that the age-related declines in expert performance are mediated by reduced engagement in practice.[34]

Applying the Expert-Performance Approach and Deliberate Practice to Medicine

How to successfully transfer the theoretical framework of expert performance with deliberate practice from music to medicine is not obvious. Children are often introduced to the domain of music with the idea that they might become expert musicians. A curriculum for each instrument, designed to gradually improve students' skills, governs the first 10 to 15 years of instruction. From the beginning, music students are encouraged to perform in front of family and friends; at higher levels of skill, they perform more complex pieces in front of audiences. Opportunities for feedback from not only teachers, but also other musicians who listen to public performances, abound. In stark contrast, in the United States and Canada, future medical doctors typically spend the first 13 years of learning in general K–12 education, and then they spend another 4 years acquiring a bachelor's degree, often studying natural science. Traditionally, full clinical training does not begin until the third year of medical school with clerkship, and only at this point do students begin to make decisions about specializing (e.g., in surgery, psychiatry, radiology, or pediatrics). This clinical training and specialization corresponds to the beginning of acquiring specialized skills in diagnosis and the execution of specific medical procedures.

Training in medicine has traditionally focused on acquiring, first, theoretical knowledge and, then, actual experience in real-world situations, where performance has consequences for patients. In the domain of medicine, the traditional focus on knowledge and neglect of gradual skill acquisition through deliberate practice is exemplified by the well-known saying about learning and performing medical procedures, "See one, do one, teach one." This adage implies virtually instantaneous mastery of new procedures among medically trained individuals; however, objective performance measures gathered when new laparoscopic techniques became available in the mid-1980s have invalidated this conventional wisdom.[35] In spite of extensive training in classical surgery, the learning curves of the experienced surgeons were typical: the reduction of significant errors in laparoscopic surgery was a function of the number of completed procedures.[36]

Just as simply watching a procedure is ineffective, so too are continuing medical education (CME) lectures and accumulated hours of professional experience. A review showed that attending CME lectures did not effect any meaningful changes in participating doctors' actual practice.[37] Similarly, other research[38,39] has *not* shown sustained benefits of longer professional experience by health care professionals after completing supervised training. Beyond some gains from the initial experience during the first years of independent practice, benefits for improved judgment from additional professional experience are very limited.[40]

There are several reasons that additional professional experience does not seem to improve performance. Availability of particular types of experience in real-world settings is typically not under the control of the learner; days, weeks, or months may pass between encounters of a particular type of patient with similar symptoms and problems—an interval hardly ideal for learning and improving skills. Medical residents enjoy the possibility of seeking advice and feedback from their supervisors, but clinicians in independent practice are less likely to have the same opportunity. Actively seeking feedback needs to be supported by better-designed learning environments[41]—for trainees and those in practice alike. Supervisors should be encouraged and trained to give specific individualized feedback that allows the resident to make appropriate changes to his or her performance through designed practice[42]; however, one challenge for supervisors is that they cannot give trainees completely accurate feedback until patients have been assigned a final diagnosis and treatments have been completed, which could, regrettably, take days, weeks, months, or even years.

One innovation through which experts can give feedback to trainees is simulation. There has been a strong interest in creating, for some professional domains of expertise, learning environments that simulate real-world environments where practice may lead to real improvements in performance. These environments allow instructors the ability not only to provide high levels of control over the situations but also to offer the trainee immediate, informative, and accurate feedback.

Developments in technology during the 20th century afforded the possibility of designing simulators for training airplane pilots and others with critical jobs (e.g., operators of nuclear reactors, drivers of trains). Newer developments have allowed for the creation of flight simulators that can reproduce the entire flight mission, including planning the flight, communicating with the airport flight controllers, and managing emergency events. One of the first meta-analyses of training in airplane simulators showed that the average effect sizes of adding simulator training to regular flight training (all trainees proceed at the same pace) were relatively small (r_{pb} around 0.1–0.2), but that effects of mastery-based training (trainees proceed only after attaining a predetermined level of performance) were substantially higher (r_{pb} around 0.5).[43(p72)] Subsequent reviews emphasized the interactions between level of skill and the fidelity of the simulator (i.e., beginners benefit more from low-fidelity simulators than higher-fidelity ones).[44] Other researchers found large benefits of brief simulator training for new procedures, but no significant benefits for general skills controlling the airplane[45,46] or landing it, especially on aircraft carriers.[47] These findings indicate that the target skill must be analyzed carefully to ensure that the simulator functionally represents the critical perceptual and control characteristics of real-world situations.

The last several decades have witnessed remarkable advances in the use of simulators in medicine. Most of the research in training has focused on preparing medical students, interns, and residents for their first medical procedures with human patients. The simulators provide trainees with an opportunity to execute a particular procedure using a device that, as much as possible, replicates a particular medical situation. Some computer-based simulations of the body (or its parts) provide feedback on how successfully trainees have inserted needles or manipulated targets. In a groundbreaking review, Issenberg and colleagues[48] analyzed learning outcomes of simulation-based training in an effort to assess which particular training conditions were transferable (i.e., associated with improved performance of the procedures outside the simulator). The most important element for effective, transferable learning was linked to having explicit performance goals. Receiving immediate, accurate feedback and repeatedly performing the assigned task were also vital elements. In a subsequent review,[49] these authors argued that these elements, shown to be essential for effective learning, corresponded to the elements of deliberate practice. They also argued that training in the simulator must be extended until each trainee reaches a predefined level of performance associated with mastery.[49]

One influential study of simulation-based medical training involved skilled surgeons performing tasks on simulators. The researchers used these experts' simulator performance as guidelines to determine mastery goals for students training with the same virtual reality simulators.[50] Authors of another, comprehensive review determined that medical education using simulators embraces best teaching practices: "distributed, structured, and deliberate practice,"[51(p336)] "appropriate mechanisms for feedback,"[51(p336)] and objective training goals. Authors of a very recent review[52] found that this type of simulation-based mastery learning is associated with increased learning compared with traditional medical education (i.e., classroom instruction and supervised performance in clinics) and results in significant transfer to clinical outcomes, such as improved patient care and health. Studies of mastery learning show that trainees' skill in performing medical procedures can be greatly improved over traditional medical education by providing the trainees with simulator training that provides immediate feedback and opportunities to repeatedly perform until they reach an objective criterion.

The Expert-Performance Approach With Deliberate Practice as Distinct From Mastery Learning

This current Perspective focuses on the expert-performance approach with deliberate practice, which is distinct from mastery learning. The concept and practice of mastery learning has a long history, beginning in the 1920s and 1930s.[53] The central idea is that K–12 students are able to attain the same learning goals, but require different amounts of time to do so.[54] Giving all students enough time to master a topic or skill (as determined by meeting some predefined test score) ensures that all students have the same or similar mastery of the prerequisites when they move on to the next educational topic.

The mastery concept makes sense within a sequential curriculum for learning skills of increasing complexity, such as in general K–12 education, which requires students to master specified knowledge and skill prerequisites to be prepared for more advanced courses in mathematics, sciences, and the humanities. The main goal of education is mastery of general knowledge and skills that are likely applicable in any profession or path available to high school graduates. In the case of medicine, the training in medical school prepares students for further training in any medical specialty. Given that continued professional education has only a very modest impact on clinical practice[37] and the accumulation of professional experience beyond the first years has only a small effect of performance,[38–40] one might question whether the effectiveness of current medical education is optimal for developing performance of medical professionals.

The expert-performance approach with deliberate practice is in many respects the opposite of general education because it starts by focusing specifically on the particular desired end product of training and experience—namely, the representative target performance of medical specialists, such as surgeons or radiologists who have patient outcomes that are superior to their peers. By analyzing the superior target performance, the expert-performance approach with deliberate practice identifies the mental structures and representations that *expert* specialists have acquired and refined during the extended period of their training and professional practice.

Several of the criteria for mastery learning[55] are consistent with some of the prerequisites for deliberate practice; these include the importance of an explicit goal for training; access to immediate, accurate, and detailed feedback; and opportunities for repetition and practice until a prespecified level of performance has been attained. In mastery learning, learning is evaluated almost entirely by the learner's attained performance on the specified criterion test. Mastery learning was developed within the theoretical framework of behaviorism and thus does not entail assessing the cognitive processes mediating the acquired performance. In direct contrast, the expert-performance approach includes an attempt to assess participants' thought processes and involves evaluating how the improved performance is mediated through and integrated with other skills and knowledge related to the final or target superior professional performance. For the expert-performance approach, the successful integration and continued refinement of different skills provide the keys to the development of high (expert) levels of complex performance.

Surgery as an Example of Expert Performance Mediated by Acquired Cognitive Representations

In this section, I describe how the expert-performance framework with deliberate practice can provide additional insights into superior performance in surgery and the associated cognitive representations mediating performance in surgery.

According to the expert-performance approach, the first goal in the scientific study of expert performance in a particular domain is to identify reproducibly superior performance in authentic contexts. The next step is either to study this performance in that context or, ideally, to capture the performance through representative tasks in the laboratory so that the superior performance can be repeatedly reproduced so as to identify its mediating characteristics and, in particular, its acquired mental representations. The final step involves creating training methods that can develop the associated cognitive representations in potential experts effectively.

Identifying expert performance in surgery

It is not easy to find activities for specific medical specialties, for which differences in objective, uncontroversial measures of patients' outcomes can be directly linked to the performance of individual clinicians. One of the best examples, however, where this link *is* possible concerns outcomes of cancer surgery.

In two particularly relevant studies, Vickers and colleagues[13,14] show that patient outcomes gradually improve as a function of the surgeons' experience with a particular procedure. They examined the surgical removal of the prostate, an especially good measure of surgical skill because "adjuvant therapy is not commonly given for prostate cancer and recurrence is not substantially affected by other aspects of postoperative care"[13(p1171)] According to their research, less experienced surgeons who completed fewer than 10 procedures were almost twice as likely to have patients with a recurrence of the cancer as compared with experienced surgeons with more than 250 completed procedures.[13] The gradual extended improvement is even more striking in another review that examined outcomes of cancers restricted to a single organ.[14] In these cases, the recurrence of cancer declined as a function of surgeons' increasing experience for the first 1,500 to 2,000 procedures, at which point the recurrence of cancer was essentially eliminated. These improvements in surgical outcomes as a function of more experience are likely related to unique characteristics of surgery. Unlike many other medical activities, the surgeons receive immediate feedback from mistakes and other unexpected problems during surgery. Further, during the subsequent hours or days the patient is in postoperative care, the surgeon often has the opportunity to diagnose problems, which might even lead to the need for immediate corrective surgery and feedback about the cause of the associated problems.

Cognitive processes that mediate surgeons' superior performance

Because the second step in the expert-performance approach is to identify how expert surgeons' thought processes differ from those of less accomplished ones, here I review these processes, showing how these thoughts provide evidence for acquired mental representations.

A common view of experts' performance, in line with traditional theories of skill acquisition, is that the experts have *automated* their performance[56,57]; thus, experts' performance, according to some traditional theories, is guided primarily by intuition.[58,59] This idea is testable: Simply interviewing experts provides an initial rough estimate of how much intuition drives performance. In one recent study,[60] investigators asked eight surgeons general questions about their decision making before, during, and after laparoscopic surgeries. Probably the most interesting conclusion was that surgeons reported that they could execute only the most straightforward cases according to simple rules. The investigators found that most laparoscopic surgeries are too unpredictable and that "even expert surgeons find themselves in situation[s] in which they must thoughtfully reevaluate their approach during surgery, evaluating alternative actions, such as the selection of different instruments or changing the position of the patient."[60(p1036)] In other words, intuition did *not* drive the surgeons' performance.

In another study, investigators asked 12 surgeons to recall one critical incident involving a particular surgery that had happened within a long time span (as many as two years prior to the interview).[61] Half of the surgeons (n = 6) did not report remembering any deliberation of alternatives; they remembered considering only one approach. The remaining 6 surgeons reported analyzing and comparing more than one solution. Given that the decisions were recalled from the past, an obvious danger is that the surgeons might not have correctly recalled all of their thoughts. A group of investigators[62] has addressed this methodological problem—essentially avoiding the problem of recall and forgetting—by observing the surgeries as they occurred. These investigators asked surgeon volunteers to predict which of their planned surgeries would likely be challenging, and the surgeons allowed the researchers to be present to observe these surgeries. The investigators interviewed the surgeons immediately after the surgery. The questions they asked focused on situations in which the surgeons were not sure what to do next.[62] The investigators identified one nonroutine decision in every case submitted to analysis.[62] The primary cognitive mechanism surgeons used to detect problems involved noticing a mismatch between their expectations based on the preoperative plan and the actual surgical situation (see Representations 1 and 3 in Figure 3). After they recognized the problem, the surgeons actively generated alternative actions and weighed their relative benefits.[62] The findings—based on information about thought processes collected immediately after a completed surgery[62]—clearly support the hypothesis that experienced surgeons have acquired refined representations for planning surgery, implementing the plan, and monitoring the surgery so they can detect mismatches.

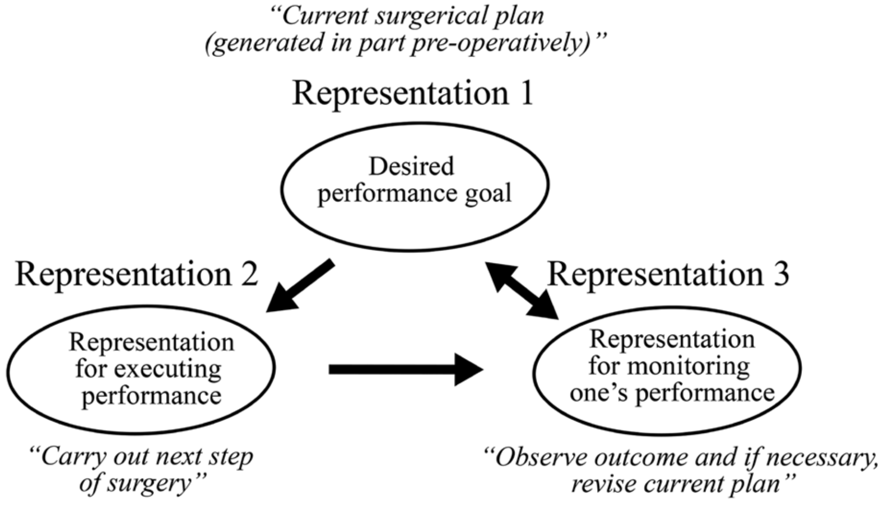

Figure 3 Three types of internal representations that mediate expert surgeons' cognitive processes during surgery. (Adapted from Figure 6, Ericsson KA. The scientific study of expert levels of performance: General implications for optimal learning and creativity. High Ability Stud. 1998;9:92.)

Consistent with these findings, reports of recalled thinking during past surgeries after a delay of months or years are unreliable—most likely because of forgetting in the interim period.

A related body of evidence supporting the premise that experts immediately recognize patterns, rather than engage in thinking, comes from some experts themselves, who report that they were not thinking while performing.[56–59] These reports are particularly frequent in sports, where athletes, who are interviewed after a competition, often report simply doing what felt right.[63] One method to empirically assess the experts' thoughts during the actual performance is to examine whether their performance relies on perceptual access to (i.e., actually seeing) the current situation while executing a particular action or whether the information is mentally represented and thus accessible from memory without the aid of perception. For example, in one study, squash players wore goggles that could instantly obstruct all vision, and their vision was occluded just after the opposing player had completed their hitting action.[64] More-skilled players were more accurate in their anticipation of the ball trajectory than less-skilled players.[64] In another study, investigators "occluded" soccer players' vision while the players were watching a video of a soccer game by unexpectedly stopping the tape and blanking the screen.[65] They found that the players' ability to accurately recall where the other relevant soccer players were on the field and where they were heading was significantly superior for more-skilled soccer players than less skilled.[65] Investigators in both of these studies showed that more-skilled and expert performers had extracted more useful and reportable information about the given situation.

Investigators have used this methodology to assess experts' ability to recall salient details of a dynamically changing environment (situation awareness) or to assess their mental representations of a situation after key data have been removed in domains other than sports.[66] For example, in simulator training, researchers have removed all relevant information and asked expert and novice air traffic controllers to recall information relevant to managing the arrival of airplanes[67] and fighter pilots to execute specific missions.[68]

Studies of situation awareness in surgery show that more-skilled surgeons are better able to access the ideal representation of information (Representation 2) relevant to the current state of the surgery. Situation awareness should decrease when external interference, such as a telephone call, interrupts a surgery. One study found that such interruptions were associated with an increased probability of errors in residents, but residents' situation awareness allowed them to discover most of their own mistakes during surgery, thus avoiding negative patient outcomes.[69] Another source of evidence for the need to monitor mental representations during critical situations (i.e., to maintain situation awareness) is based on observations of surgeons whose surgeries had successful or unsuccessful outcomes. An analysis of surgical errors during a particular laparoscopic procedure showed that the injuries were due to misperception of the anatomical structures rather than technical errors, indicating that surgeons had developed an inadequate mental representation.[70] According to another study,[71] surgeons of different specialties reported slowing or even halting action at critical points during the surgery when they increased their attention. This study also reported evidence that surgeons decreased their attention and situation awareness during so-called "easy" operations and that these surgeries were associated with near misses or errors.[71] Similarly, Bann and colleagues[72(p414)] have argued that "senior surgeons are more prone to slips and lapses." In sum, findings from these studies[70,72] support the idea of automatic habitual processing (low situation awareness) in some standard surgeries by experienced surgeons; however, I argue that this type of processing is not a sign of expertise but, rather, a sign of reduced attention that may be leading to an increased risk of error. Consistent with research on expert performance, the superior performance of experienced surgeons is associated with refined representations to plan, to execute, and to monitor surgical states, which allows these surgeons to be prepared for unexpected outcomes and carefully consider the best solutions to problem situations.[2,24]

Developing and refining mental representations: Implications for training

The evidence for developing mental representations to refer to in planning for, executing, and monitoring surgeries raises questions about how training might be designed to help learners develop these representations more effectively. Several findings support the potential benefits of training outside the operating room. Superior skill in identifying relevant anatomical structures during laparoscopic procedures is associated with reduced risks of injuring adjacent tissues, ducts, and vessels.[70] Recently, a researcher presented surgeons of differing experience with pictures from laparoscopic surgeries taken just prior to making a surgical cut.[73] The surgeons were instructed to mark the spot where they would cut for the surgery. Although the author observed systematic differences between the groups (more experienced surgeons recommended different initial cuts than less experienced surgeons), no independent gold standard was available to demarcate the best location for the proposed cut. Still, the findings indicate that the skill of deciding where to make cuts during surgery should be taught directly during training, especially for less experienced surgeons. Finally, research on supportive skills for laparoscopic surgery is available: Experienced laparoscopic surgeons were interviewed about their methods for manipulating tissues and generating superior views via the camera to determine the tissue planes.[74] In sum, these findings support the existence of mental representations and the ability to access them outside the operating room, which has implications for designing medical education to support their development.

If clinical instructors were able to review videos of prior surgeries, extract recordings of particularly relevant situations, and store these recordings in a library, they would be able to develop in trainees the ability to identify anatomical structures. For example, a trainee could view a frozen screen and draw the most appropriate cut as rapidly as possible without sacrificing accuracy. A computer could analyze responses, providing trainees with immediate feedback and, later, opportunities to perform similar tasks at the same or higher levels of difficulty.

Creating feedback loops that allow for improvements of current surgery performance

One of the most interesting developments in medicine is the current effort to carefully document a trainee's behavior during surgery to identify near misses and mistakes. In one case study, a Canadian neurosurgeon named Mark Bernstein worked with his team to record and enter all errors into a computer after every elective surgery he performed (n = over 1,000) from 2000 to 2006.[75] He even included minor mistakes, "such as dropping of a sponge."[75(p1076)] These descriptions were analyzed to relate them to complications so as to identify preventable errors that caused the complications. Following this published analysis, Bernstein continued to record his errors from August 2006 to May 2013,[76] and the error rates associated with this latter period were compared with the earlier period. The average number of errors and error-related complications fell by over 50% during the second period. This reduction in errors, especially during the first years of recording (2001–2002), suggests that the mere act of attending to errors to record them may have an effect on their subsequent occurrence.

Perhaps one of the most exciting developments in the measurement of behavior during surgery is the systematic video recording of surgeries followed by detailed analyses of the videotapes.[77] This method—review by, ideally, an independent expert blind to the identity of the particular surgical team, to avoid any potential bias in the coding of errors[77]—can be used to assess weaknesses in a surgeon's current performance, and can thus serve as the starting point for training surgeons using deliberate practice. An essential prerequisite for communication between teachers and students is the creation of detailed coding schemes, as illustrated by one for laparoscopic gastric bypass surgery that has been shown to be reliable and valid.[78] Using such a coding scheme should allow the identification of particular technical problems so that trainees may practice avoiding these and receive accurate feedback to improve—before entering an actual operating room.

This type of video recording, as a means to identify training goals for improvement, is not limited to less experienced surgeons. In a particularly interesting study, Birkmeyer and colleagues[79] collected a video of a single bariatric surgery from each of the participating surgeons. They rated each surgeon's surgical skill and discovered post hoc that the ratings were related to the complication rates for the same surgeon's normal surgical practices.[79] The findings of this study indicate that it may be possible to reduce complication rates for patients by training the surgeons to increase their skill in performing their surgeries.

The methodology of using video recordings and their independent assessment seems to offer a potential feedback loop through which weaknesses and potential problems can be identified. These areas requiring improvement could then be addressed through targeted training focused on the relevant technical skills, the perceptual skills necessary to sense and understand the critical anatomical structures, the ability to plan the surgery, and/or the capacity to detect and deal with unexpected deviations or events.[80] Recognizing the development of refined mental representations in skilled surgeons may have implications for learning and teaching, for introducing and acquiring, the skills necessary for a particular surgical procedure.

How to introduce learning of surgical procedures

When surgical trainees are trained through the *mastery learning* approach, they receive general instruction about a particular procedure and then are allowed to perform the procedure with a simulator. The simulator provides feedback about the accuracy of trainees' actions and, often, the amount of time they took to complete the procedure. The trainees then repeat the procedure until they have reached a predetermined proficiency level. A recent review shows that simulator-trained participants perform better than the control participants when tested on the simulator, on animal models, and even on human patients who lack complicating factors.[81] These findings show that simulator training leads to superior performance when tested with conditions similar to training or simple clinical cases, but so far this type of training has not been designed to build and shape the superior surgical performance of independent surgeons.

The *expert-performance* approach with deliberate practice demands that the required performance on the simulator be an extremely close approximation of the relevant aspects of the procedure on an actual patient.[2] The trainee's initial performance should establish a good representation of the procedure, and each subsequent performance can be reviewed and, with more training, refined until the trainee reaches highly skilled levels. To illustrate, children do not spontaneously adopt the best postures and techniques when playing the piano, so their teachers instruct them and closely monitor their playing until the children acquire the correct fundamental actions and postures. Failure to adopt the correct fundamental actions will limit the individual's ability to perform technically difficult music pieces (also, incorrect fundamental technique often leads to overuse injuries among adult professional musicians). Similarly, surgical trainees using simulators should receive supervised instruction about acquiring the correct fundamental technique to maximize their future skill. Currently, trainees are allowed to execute the procedure on the simulator in whatever manner feels most natural to them; they typically receive no information about more advanced techniques that might be useful in successfully completing more challenging future surgeries.

In a recent study,[82] investigators examined the possibility of giving trainees feedback so they could attain the correct fundamental techniques. This study compared two groups of inexperienced surgeons, all of whom trained on a simulator to perform a laparoscopic cholecystectomy (LC). One group received feedback on their weakness and experienced 30 minutes of training targeting that weakness (i.e., deliberate practice) before they completed a second LC, whereas the other group watched surgical tutorials unrelated to laparoscopy or cholecystectomy for 30 minutes. Although both groups showed improved performance on the simulator and on a porcine model, the deliberate practice group attained a higher quality of simulator performance and showed superior transfer to real tissue.[82]

Expert performance in the surgical environment requires the ability to execute a wide range of emergency procedures. For some of these procedures, the primary emphasis is on the speed in which simple sequences of actions are executed; in such procedures, entrenched action sequences are desirable. Elizabeth Hunt and colleagues[83] developed a training procedure that they named "rapid cycle deliberate practice" for resuscitation. After a team of trainees received instruction on performing the procedure, their time to initiate heart compression and other critical events was recorded. Rather than having the team discover more effective methods through practice and discussion, the instructor next provided step-by-step guidance on the best procedure for initiating heart compressions as fast as possible. After completed "rapid cycle deliberate practice," in which the team practiced the procedure over and over and the instructor provided guidance on improving weaknesses, the trainees were almost four times as likely to start heart compressions within one minute of loss of pulse, a factor related to successful resuscitation.[83]

An important question to ask when considering the expert-performance perspective is whether the cognitive representations used to perform surgical procedures in the simulator match mental representations when working on actual patients in the operating room. Research so far is inconclusive. Recent tests comparing experienced and less-skilled surgeons' performances on simulated cases have shown that performance in simulation centers correlates to performance both on other simulated cases and with actual patients in operating rooms.[84] Another group of researchers have found a significant difference in performance on simulated catheterization cases in a laboratory between novices and experienced interventional cardiologists, but not between two groups of experienced cardiologists even when the cardiologists in the experienced group had large differences in the number of completed therapeutic procedures.[85] Other researchers, studying coronary angiography, rated videos of catheterization procedures performed on actual patients and on simulated cases in the laboratory.[86] They found that experience improved performance on actual patients, but not on the simulator. Collecting think-aloud protocols and immediate retrospective reports[24,87] from surgeons performing both in the operating room and in the simulation lab should enable the comparison of thought processes and mental representations used in the two situations. In turn, these comparisons should enable the refinement of simulators such that training tasks in the simulator require the trainee to conduct the procedure in the simulator with the same or very similar actions used on actual patients.

At least one general training approach minimizes the problems associated with acquiring representations during simulator training that differ from those used in the operating room. Palter and Grantcharov[88] centered their training on an analysis of videotapes of individual's surgical performance on actual patients. After each completed surgery, an instructor reviewed the videotape to identify weaknesses and then assigned targeted training in the simulator for remediating these weaknesses. To assess the effects of this type of training, the investigators compared two groups of novice surgical residents performing LCs in the operating room. One group of residents was assigned practice tasks in the simulator based on an analysis of their videos of their first surgery so they could focus on improving the weakest aspects of their performance. Another group of residents, who served as the control group, were given informal feedback as is traditionally done in surgery education. After this experimental intervention, the two groups performed a second (also videotaped) LC in the operating room. Blind analysis of the videotaped performance showed that the deliberate practice group was now superior to the control group; the deliberate practice group in fact improved to such an extent that the distributions of performance for the two groups did not even overlap.[88] This intervention is a particularly effective demonstration of how all aspects of deliberate practice can be applied in the surgical domain. Instructors applying this training method would assess the actual surgery in the operating room for weaknesses and design the training in the simulator to improve those weaknesses.

Maintaining surgical performance

One of the most consistent predictors of surgical outcomes is the volume of surgeries completed by a given surgeon. Recent studies of surgical outcomes have shown that the length of time between consecutive surgeries of a given type is significantly related to patient outcomes—the longer the gap, the worse the patient outcomes.[89–91] This pattern is consistent with the earlier reviewed studies[29–34] on other types of skills.

Cognitive Processes That Mediate Improvements in Performance in Other Medical Activities

The permitted length of this Perspective does not permit a comprehensive review of all the different types of medical activities and tasks; therefore, I have focused the remainder of my Perspective on two medical tasks—namely, interpreting X-rays and interviewing patients, for which adapting the expert-performance approach with deliberate practice is markedly different. An important difference between the two tasks is related to their different levels of complexity. Interpretation of a variety of static X-ray images entails examining fixed images that can be easily removed from the original radiology clinic and presented to experts or trainees, including medical students, interns, residents, and radiologists, with few or no changes, thus creating a standardized means of capturing the essential elements of the task. In contrast, patient–doctor meetings involve an extended interaction that depend on the particular patient and his or her problems as well as the associated responses of each doctor.

Performance of X-ray interpretation

Measuring the performance of interpreting X-rays is relatively easy for mammograms. The general method is to collect a number of X-rays from actual patients and then wait a sufficient amount of time to procure a final diagnosis for each. Given the low rate of cancer cases, collecting X-ray images from mammograms requires waiting long enough to amass a sufficient number of pathological cases and then mixing in a number of normal cases.

A recent review shows that the accuracy of interpreting mammograms as screens for breast cancer increases on average as a function of the number of completed interpretations; specifically, radiologists who have not completed a fellowship incorrectly call fewer and fewer women in for further testing (false positives) over their first three years of practice (33 in year 1; 19 in year 3)—without any changes in their rate of missing cancers.[92] Of particular relevance for training effectiveness is the finding that radiologists who completed a radiology fellowship *already* performed at the expert level during their first year of independent practice.[92] Although this finding is only correlational, it suggests that the period of fellowship training in radiology affords the fellows the opportunity to improve their diagnostic performance prior to the start of independent practice.

Interestingly, while both this study[92] and another[93] show that experienced mammographers' performance is reproducibly superior to that of less experienced mammographers and that experienced mammographers meet the criteria for expert performance, both also report that even experienced mammographers have large individual differences in the accuracy of their diagnoses. Researchers have not yet been able to specify the nature of these individual differences, which would help clinical teachers individualize training in mammography.[94]

Using a particularly promising approach to describe the processes mediating superior performance, investigators asked highly experienced and less experienced individuals to think aloud while making their diagnoses.[95,96] In the more recent study,[96] investigators asked 10 radiologists and 10 radiology residents to think aloud while diagnosing the same mammograms. The analysis of the think-aloud protocols indicates that cognitive processes associated with more experience are associated with superior mental representations of normal cases, which allow experts to carefully analyze findings in all mammograms. The authors of this study[96] also found that individuals with higher levels of expertise were more able to self-regulate and apply successful search and reasoning strategies. These findings indicate that it would be fruitful to study if and how experienced mammographers engage in learning with immediate feedback, and what their thinking and learning processes are, especially when they make a mistake.

Another group of researchers[97] analyzed the incorrect diagnoses of a relatively large group of radiologists (n = 92). Higher-performing mammographers identified the types of cases and lesions that lower-performing mammographers missed. In another study,[98] investigators examined the effect of feedback on how accurately mammographers detected cancer; these investigators also analyzed the results of biopsies ordered based on an original reading of the X-ray. A higher frequency of workups was associated with a significantly higher cancer detection rate, but the frequency of women being asked to endure an unnecessary biopsy (i.e., of false positives) was also higher. These two findings have helped to establish not only review procedures that are associated with higher accuracy in diagnosis but also means of targeted practice that allow lower-performing radiologists to improve their performance by identifying cancer in a variety of cases, even at the level of their higher-performing peers.

The traditional training of radiologists is based on the apprentice model, through which the apprentice, typically a resident, examines submitted X-rays to generate a preliminary diagnosis. Subsequently, the resident's supervisor examines the X-ray and gives an official diagnosis, which serves as the gold standard. Nodine and colleagues[93] administered a test to radiology residents and fellows and their supervisors (mammographers) on interpreting a number of mammograms. The accuracy of the breast cancer diagnoses increased as a logarithmic function of the number of mammograms that the individuals had encountered during their professional experience and reached a stable level of accuracy (though this level is far from perfect) at around 10,000 mammograms, which is generally the number of mammograms completed by the supervising mammographers.

In the current training system, supervisors must make their decisions without knowing the correct diagnosis because a couple of years may pass before they can infer with a high degree of confidence whether the patient had cancer or was cancer free at the time of the submitted X-ray. By establishing a library with old X-rays, relevant patient information, and final diagnoses (to serve as the gold standard), radiology instructors may be able to design a learning environment that provides cases and immediate feedback on proposed diagnoses.[99] Such a library could then be computerized, such that X-rays and diagnoses are indexed. The assembled library of cases could thus serve the dual purpose of measuring performance for interpreting X-rays and teaching trainees about different types of X-rays, such as mammograms or bone lesions. If instructors observe weaknesses for certain features or particular types of X-rays, they could (or a computer program could) generate training sets in which practice items are organized by difficulty to make deliberate practice possible. In fact, one group of researchers, Pusic and colleagues, developed a case bank of 234 digital items in an initial study,[100] and they were able to show that the accuracy of diagnosis for the items in the library was significantly superior for radiologists compared with pediatric fellows, and stepwise, for pediatric fellows compared with medical students. In a related study[101] focused on training, they designed a practice environment in which residents were able to get immediate feedback on each completed diagnosis. With practice, the residents increased their diagnostic accuracy as a function of the number of radiographs that they had studied. On the basis of this practice curve, Pusic and colleagues estimated the number of additional practice X-rays necessary to reach the accuracy demonstrated by the attending pediatricians.

Another recent study[102] demonstrated the effectiveness of receiving immediate feedback on diagnoses of mammograms displayed through a DVD. The study randomly assigned trainees to getting training with the DVD or being members of a control group with no additional activity. The DVD group performed significantly better than the control group on a subsequent test with different mammograms. It should be possible to go beyond simply presenting all trainees with the same sequence of mammograms and giving immediate feedback on each case. For example, clinical instructors should be able to assess weaknesses in the trainees' performances by examining their cognitive representations collected either through an analysis of their think-aloud protocols or through their sketches of recalled mammograms. This type of individualized coaching would contain all the essential elements of deliberate practice.

Clinical interactions with patients

An important aspect of most professional medical doctors' everyday activity involves communication with patients. These interactions with patients[103] include interviews to elicit information about patients' medical problems, discussions to educate patients about how their problems might be improved by treatment, and of particular importance, conversations to jointly develop a plan for care. Clear evidence shows that adherence to the recommended treatment plan, including taking prescribed medications, influences patient outcomes for chronic diseases.[104,105] Improving a doctor's communication skills, therefore, likely increases his or her patients' adherence to treatment plans and, in turn, improves outcomes. Similarly, research has shown that cancer patients' understanding of their disease and its prognosis, which is tied to doctors' communication skills, is related to better decisions about end-of-life treatments.[106] A review examining patients treated by professional palliative care specialists who experienced extended training in, specifically, communicating with cancer patients demonstrated significant beneficial effects on patient outcomes.[107] At the same time, other recent studies have failed to demonstrate increased patient satisfaction or improved patient outcomes after physicians experienced either short-term training in communicating with patients with serious illness[108] or general training in hospitalist communication skills.[109] In one of the studies[109] the training consisted only of three 90-minute workshops, but in the other[108] the training lasted four days and even included skills practice with standardized patients. Notably, only with the more extended training did the investigators observe significant effects on behavior *during* the training,[108] but these effects did not transfer to the clinical environment. An insightful comment[110] proposed the need for new and innovative ways to teach communication skills and argued for a tighter connection between measured clinical performance and designed practice—just as I have advocated earlier in this Perspective.

The idea of effective communication with patients as a set of teachable skills implies training adults (i.e., making changes to preexisting adult behaviors); therefore, it seems plausible that workshops or even a four-day training will be insufficient for attaining substantial improvement in everyday performance.[2] These findings are consistent with the earlier observations that continued professional medical education courses did not influence behavior in the clinic,[37] and that mere professional experience after the first couple of years of independent practice or deliberate practice rarely improves objective performance.[38–40,111,112] Wouda and van de Wiel[103] make the important point that medical students already enter medical school with a number of previously acquired habits and skills for communicating with other people; these habits are unlikely to change with mere experience, and they are difficult to modify even through instruction or modeling. These authors[103] argue that the most effective methods of influencing communication skills involve video recording a physician's or trainee's interactions with peers, relatives, and real patients. Instructors can then view the videotapes and identify key weaknesses and problems that they can then address directly with the physician or trainee. In this way, the teacher's one-on-one guidance may not differ much from piano teachers' and tennis coaches' directed work with individuals. In all three scenarios, the instructor identifies an area to be improved and either instructs the trainee to engage independently in deliberate practice of appropriate tasks or spends an hour interacting with the trainee. At first the clinical instructor may provide simple situations, so the trainee can anticipate what will happen. For example, during the training of backhand volleys, the trainee might be standing at the net waiting for an easy hit that the coach delivers in a consistent manner. With increased success, the coach will make serves more challenging, and eventually the player and the coach will engage in a volley in which the trainee must be prepared for backhand volleys during regular playing. This method—that is, integrating a deliberately practiced skill into normal execution of the activity—can be applied to improving communication with patients. After understanding and practicing to eliminate their key weaknesses, students would engage in more (tape-recorded) patient interviews with the goal of gaining information or preparing the patient for the plan of care. Importantly, the improved communication skills must be integrated into the trainee's increasingly refined mental representations not only for encoding and combining patient information but also for perceiving and responding to patients' reactions and expectations. Consequently, the development of superb communication skills is an extended process, and the recommendation is that doctors design a plan for continued education and training throughout their careers to improve the effectiveness of their communication skills. A recent report[113] describes efforts to implement communication-skills training for residents based on video recordings of outpatient consultations. This process of reshaping the medical education system will be long, and the first step involves training the supervisors so they can serve the residents as qualified and effective teachers.

In Sum

The research on expert performance differs from that on general education, which focuses on the acquisition of new knowledge and general rules that educators hope will be widely applicable in many professional domains. The theoretical framework of expert performance also differs from the theories of expertise that focus on the knowledge and rules acquired prior to or during active practice. According to expertise theories, pattern matching and effortlessly retrieved memories of previously executed actions eventually, naturally replace knowledge and consideration of rules. A finding that is inconsistent with these theories indicates that new knowledge encountered at CME seminars and conferences is not effortlessly converted into changes in habitual behavior in the clinic.[37] Furthermore, research shows that additional professional experience with familiar tasks does not consistently improve accuracy of performance[38–40] but, rather, primarily makes the associated action sequences consistent, efficient, and nearly effortless. Instead, improved performance is related to goal-directed training with immediate feedback, as suggested by the expert-performance approach with deliberate practice. Effective practice involves the refinement of mental representations during training activities through which individuals attempt to go beyond their current habitual performance by trying to attain higher performance goals. To facilitate these gradual improvements in performance, a long-term commitment to monitor performance in the clinic is necessary for integrating and transferring the skills and knowledge gained through corrective training and feedback. This training process will be more effective and reliable with the help of a supervising teacher.

This understanding of how to improve medical performance could have implications for the selection of medical students and resident applicants; that is, performance on basic tests of perceptual-motor and spatial performance for medical school applicants and initial performance on relevant simulators for residency applicants could help determine admission or placement.[114] This proposal depends on the assumption that tests of basic abilities measure prerequisite abilities for attaining more advanced motor skills. The results of one of the first studies[115] to demonstrate this relationship between simulator performance and spatial ability cast doubt on this assumption. The surgical residents with lower scores on the spatial ability test were able to eventually achieve a simulated performance comparable to that of the high-ability residents. A subsequent study by the same research group examining dental students showed that "after 10 minutes of supervised practice and feedback,"[116(p756)] students with the lower visual–spatial scores performed as well as those with higher test scores.

Although performance on basic tests measuring spatial ability,[117] as well as video game experience,[118] has been found to significantly predict initial simulator performance, individual differences in performance on simulators decrease with extended training, and, likewise, the correlations between basic abilities and simulator performance for novices change as a function of level of acquired skills.[119] Even more importantly, individual differences in simulator performance do not seem to transfer significantly to the operating room.[120,121] Investigators tested the spatial abilities of experienced surgeons and found that their scores did not significantly correlate or account for individual differences in surgical performance,[116] which led the investigators to conclude that "practice and surgical experience appear to obviate the impact of innate abilities."[116(p757)] These findings from surgery align with those (discussed earlier) that fail to show a tight relationship between simulator performance and clinical performance at the individual level.[84–86] They also support the general pattern observed across a wide range of domains of expertise.[122]

When novices begin a new activity in any new domain, they must rely on their existing skills and abilities, but as their skills are constructed during teacher-led practice and as they acquire appropriate representations to support their superior performance, the correlations between actual performance and basic ability fall to insignificance. Future research on the acquisition of the representation of superior performance in the operating room will help medical educators understand the apparent nonrelationship between initial performance in the simulator and eventual expert surgical performance.

The focus of the expert-performance framework is on the highest levels of observed performance in a domain, such as a medical specialty. Unfortunately, only a small number of studies have analyzed the performance of medical specialists through the methods commonly used to assess the structure of either expert performance or the training history of elite performers in other domains of expertise (e.g., music, sports). I believe that such studies, if/when they are conducted, will show that elite performers have acquired mental representations and fundamental skills in a manner that allows them to use the foundational skills to integrate improvements and build toward the mental representation of the ideal performance. Traditional professional education has not designed sufficient opportunities for this type of slow acquisition and refinement of skills. For example, in preparing for their first surgical procedure in the clinic, trainees may have spent thousands of hours acquiring knowledge and general rules, but only a handful of hours performing the actual procedure. In other domains of expertise, such as music, ballet, chess, and sports, the ratio between practical or technical training and theoretical training is reversed.

Once academic medicine recognizes that medical interns and residents may need to practice in designed training environments considerably longer than they currently do in order to attain the superior skills that are desirable—necessary even—for independent clinical practice, the community might begin to reform medical training. For example, initial training in fundamental skills (e.g., in the execution of surgical procedures, in interviewing patients, and in making perception-based diagnoses) may begin much sooner. The availability of videos and simulators should enable the identification of procedures for which training could begin early. Without risks to patients, medical students and residents could benefit from hundreds of hours of practice with fundamental techniques in simulators. They could develop perceptual and spatial skills from training with deliberate practice using videos of procedures collected in a library. Another benefit of articulating the particular skills required for medical students and residents is that objective tests for these skills would need to be specified, which, in turn, would permit the design of training environments that would provide rich opportunities for motivated trainees to acquire the fundamental skills at their own pace (whether before or during medical school or residency).

The new interest in improving the effectiveness of medical education and in simulation training offers a timely opportunity to motivate the collection and analysis of objective and detailed data on medical performance by individuals and teams. The expert-performance framework offers a general approach for monitoring and facilitating the development of mental representations and acquired skills which trainees can use to mediate superior individual performance. Identifying and analyzing reproducibly superior clinical performance should enable medical educators to design or "reverse engineer" training that will effectively develop this performance and the associated representations. When medical students, interns, and residents have acquired the necessary set of mental representations, they will have become self-regulated learners—that is, members of the medical community who have the tools to improve their and their team members' performances over their entire professional careers.

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Teaching and Learning Moments

BLOG

Compliments From a White Coat

"Became a bit tearful when topic of weight was broached." There was nothing of note in Kayla's prior records, except this one phrase. Kayla was a healthy 15-year-old girl presenting for a well-child check. She was the last patient of the day in our busy pediatrics clinic.

"We'll just go in together for this one," said Megan, a second-year resident, aware of the late hour. "And I'll do most of the talking."

Kayla was lively but reserved. She sat up straight but looked slightly down. She smiled brilliantly but only four-fifths of the way. She was fairly overweight but far from obese. Kayla was a pretty young girl with a kind, gentle energy … but she was probably not going to be voted best-looking in her high school yearbook.

Kayla's mother, on the other hand, could have been a former prom queen. I recalled another attractive woman who had brought in her daughter for an unusual evaluation. "Can you get rid of the spots on her face?" she had asked. "They make her look ugly."

Freckles were the chief complaint.

Kayla's mother had no complaints. She was supportive and warm. She made corny jokes *that Kayla laughed at*. And she exhibited an appropriate motherly pride.

At one point, Megan asked Kayla, "What do you like to do?"

"Well, I like to play soccer, write poetry, and volunteer with an organization that provides school supplies to underprivileged children."

"Oh c'mon honey," her mom chuckled, shaking her head. "'Volunteer with?' Tell them the whole thing."

"I founded it," Kayla said quietly.

We were in the presence of both an impressive teenager and a heartwarming mother–daughter relationship.

Megan eventually had Kayla's mother step outside. It was time for the infamous doctor–adolescent confidential chat. Drugs? No. Sex? No. Body image? Here, Kayla became visibly uncomfortable. Her speech faltered. And then, in what was one of the more memorable human moments I've ever witnessed, Megan interrupted her, locked eyes, and said, "You are a *beautiful* girl." She paused. "You *are*." And oh did she mean it.

"Thank you," Kayla whispered. Her tears this time were of a different kind.

I imagine that Kayla's mother, like many loving mothers, had praised her similarly in the past. And I imagine that Kayla, like many teenaged daughters, had swallowed it with a nice-sized grain of salt. But here was a complete stranger, not to mention someone of relatively similar age and physical features to her mother, voicing the same genuine compliment. That alone, I believe, had a uniquely meaningful effect.

However, this wasn't just any human moment. Megan was wearing a white coat, and Kayla was sitting on an exam table. Did Megan's words carry some added authority given her, well … *authoritative* role? I'd like to think so.

Medical school doesn't formally teach "when appropriate, compliment your patients," and it certainly doesn't frame the sort of unbridled emotion Megan briefly exuded as a potential therapeutic tool. This was the type of lesson that had to be shown and not told. It was medicine's hidden curriculum at its finest.

I have no delusions that Megan's words were the magic bullet to Kayla's body image issues. But Megan—Dr. Brady to Kayla—may very well have helped treat the only problem our patient presented with that day.

Author's Note: The names and personal information in this essay have been changed to protect the identities of the individuals described.

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An AM Rounds blog post on this article is available at academicmedicineblog.org.