EFFORTFUL STUDY is the key to achieving success in chess, classical music, soccer and many other fields. New research has indicated that motivation is a more important factor than innate ability.

THE EXPERT MIND

Studies of the mental processes of chess grandmasters have revealed clues to how people become experts in other fields as well

By Philip E. Ross

A man walks along the inside of a circle of chess tables, glancing at each for two or three seconds before making his move. On the outer rim, dozens of amateurs sit pondering their replies until he completes the circuit. The year is 1909, the man is José Raúl Capablanca of Cuba, and the result is a whitewash: 28 wins in as many games. The exhibition was part of a tour in which Capablanca won 168 games in a row.

How did he play so well, so quickly? And how far ahead could he calculate under such constraints? "I see only one move ahead," Capablanca is said to have answered, "but it is always the correct one."

He thus put in a nutshell what a century of psychological research has subsequently established: much of the chess master's advantage over the novice derives from the first few seconds of thought. This rapid, knowledge-guided perception, sometimes called apperception, can be seen in experts in other fields as well. Just as a master can recall all the moves in a game he has played, so can an accomplished musician often reconstruct the score to a sonata heard just once. And just as the chess master often finds the best move in a flash, an expert physician can sometimes make an accurate diagnosis within moments of laying eyes on a patient.

But how do the experts in these various subjects acquire their extraordinary skills? How much can be credited to innate talent and how much to intensive training? Psychologists have sought answers in studies of chess masters. The collected results of a century of such research have led to new theories explaining how the mind organizes and retrieves information. What is more, this research may have important implications for educators. Perhaps the same techniques used by chess players to hone their skills could be applied in the classroom to teach reading, writing and arithmetic.

The *Drosophila* of Cognitive Science

THE HISTORY of human expertise begins with hunting, a skill that was crucial to the survival of our early ancestors. The mature hunter knows not only where the lion has been; he can also infer where it will go. Tracking skill increases, as repeated studies show, from childhood onward, rising in "a linear relationship, all the way out to the mid-30s, when it tops out," says

ETHAN HILL

John Bock, an anthropologist at California State University, Fullerton. It takes less time to train a brain surgeon.

Without a demonstrably immense superiority in skill over the novice, there can be no true experts, only laypeople with imposing credentials. Such, alas, are all too common. Rigorous studies in the past two decades have shown that professional stock pickers invest no more successfully than amateurs, that noted connoisseurs distinguish wines hardly better than yokels, and that highly credentialed psychiatric therapists help patients no more than colleagues with less advanced degrees. And even when expertise undoubtedly exists—as in, say, teaching or business management—it is often hard to measure, let alone explain.

Skill at chess, however, can be measured, broken into components, subjected to laboratory experiments and readily observed in its natural environment, the tournament hall. It is for those reasons that chess has served as the greatest single test bed for theories of thinking—the "*Drosophila* of cognitive science," as it has been called.

The measurement of chess skill has been taken further than similar attempts with any other game, sport or competitive activity. Statistical formulas weigh a player's recent results over older ones and discount successes according to the strength of one's opponents. The results are ratings that predict the outcomes of games with remarkable reliability. If player A outrates player B by 200 points, then A will on average beat B 75 percent of the time. This prediction holds true whether the players are top-ranked or merely ordinary. Garry Kasparov, the Russian grandmaster who has a rating of 2812, will win 75 percent of his games against the 100th-ranked grandmaster, Jan Timman of the Netherlands, who has a rating of 2616. Similarly, a U.S. tournament player rated 1200 (about the median) will win 75 percent of the time against someone rated 1000 (about the 40th percentile). Ratings allow psychologists to assess expertise by performance rather than reputation and to track changes in a given player's skill over the course of his or her career.

Another reason why cognitive scientists chose chess as their model—and not billiards, say, or bridge—is the game's reputation as, in German poet Johann Wolfgang von Goethe's words, "the touchstone of the intellect." The feats of chess masters have long been ascribed to nearly magical mental powers. This magic shines brightest in the so-called blindfold games in which the players are not allowed to see the board. In 1894 French psychologist Alfred Binet, the co-inventor of the first intelligence test, asked chess masters to describe how they played such games. He began with the hypothesis that they achieved an almost photographic image of the board, but he soon concluded that the visualization was much more abstract. Rather than seeing the knight's mane or the grain of the wood from which it is made, the master calls up only a general knowledge of where the piece stands in relation to other elements of the position. It is the same kind of implicit knowledge that the commuter has of the stops on a subway line.

Much of the chess master's advantage over the novice derives from the FIRST FEW SECONDS OF THOUGHT.

The blindfolded master supplements such knowledge with details of the game at hand as well as with recollections of salient aspects of past games. Let us say he has somehow forgotten the precise position of a pawn. He can find it, as it were, by considering the stereotyped strategy of the opening—a well-studied phase of the game with a relatively limited number of options. Or he can remember the logic behind one of his earlier moves—say, by reasoning: "I could not capture his bishop two moves ago; therefore, that pawn must have been standing in the way. . . ." He does not have to remember every detail at all times, because he can reconstruct any particular detail whenever he wishes by tapping a well-organized system of connections.

Of course, if the possession of such intricately structured knowledge explains not only success at blindfold play but also other abilities of chess masters, such as calculation and planning, then expertise in the game would depend not so much on innate abilities as on specialized training. Dutch psychologist Adriaan de Groot, himself a chess master, confirmed this notion in 1938, when he took advantage of the staging of a great international tournament in Holland to compare average and strong players with the world's leading grandmasters. One way he did so was to ask the players to describe their

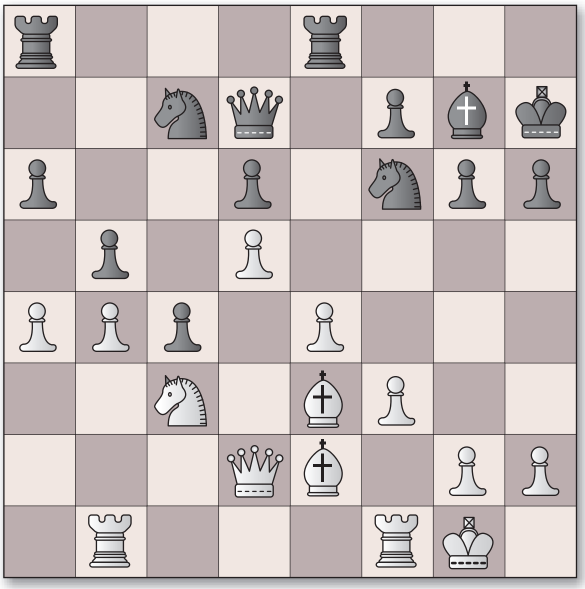
Overview/*Lessons from Chess*

- Because skill at chess can be easily measured and subjected to laboratory experiments, the game has become an important test bed for theories in cognitive science.
- Researchers have found evidence that chess grandmasters rely on a vast store of knowledge of game positions. Some scientists have theorized that grandmasters organize the information in chunks, which can be quickly retrieved from long-term memory and manipulated in working memory.
- To accumulate this body of structured knowledge, grandmasters typically engage in years of effortful study, continually tackling challenges that lie just beyond their competence. The top performers in music, mathematics and sports appear to gain their expertise in the same way, motivated by competition and the joy of victory.

A GRANDMASTER'S MEMORY

Experiments indicate that the memory of chess masters is tuned to typical game positions. In 13 studies conducted between 1973 and 1996 (the results were compiled in a review article published in 1996), players at various skill levels were shown positions from actual games (*a*) and positions obtained by randomly shuffling the pieces (*b*). After observing the positions for 10 seconds or less, the players were asked to reconstruct them from memory. The results (*graph at bottom*) showed that chess masters (with ratings of 2200 or higher) and grandmasters (generally 2500 or higher) were significantly better than weaker players at recalling the game positions but only marginally better at remembering the random positions. This finely tuned long-term memory appears to be crucial to chess expertise.

a



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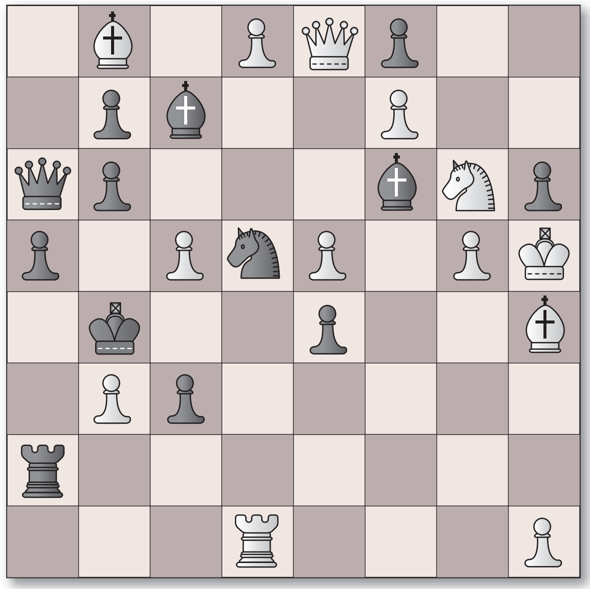
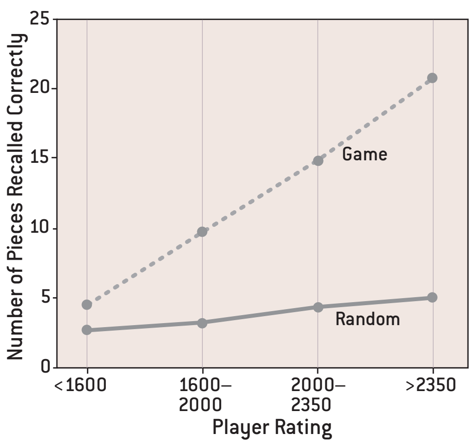
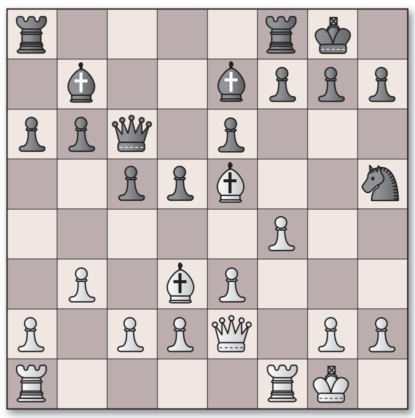




A structured knowledge of chess positions enables a grandmaster to spot the correct move quickly. The position at the right comes from a famous 1889 game between Emanuel Lasker (*white*) and Johann Bauer (*black*). Although a novice player would have to analyze the position extensively to see the winning move for white, any grandmaster would immediately recognize it. The correct move is shown on page 71.

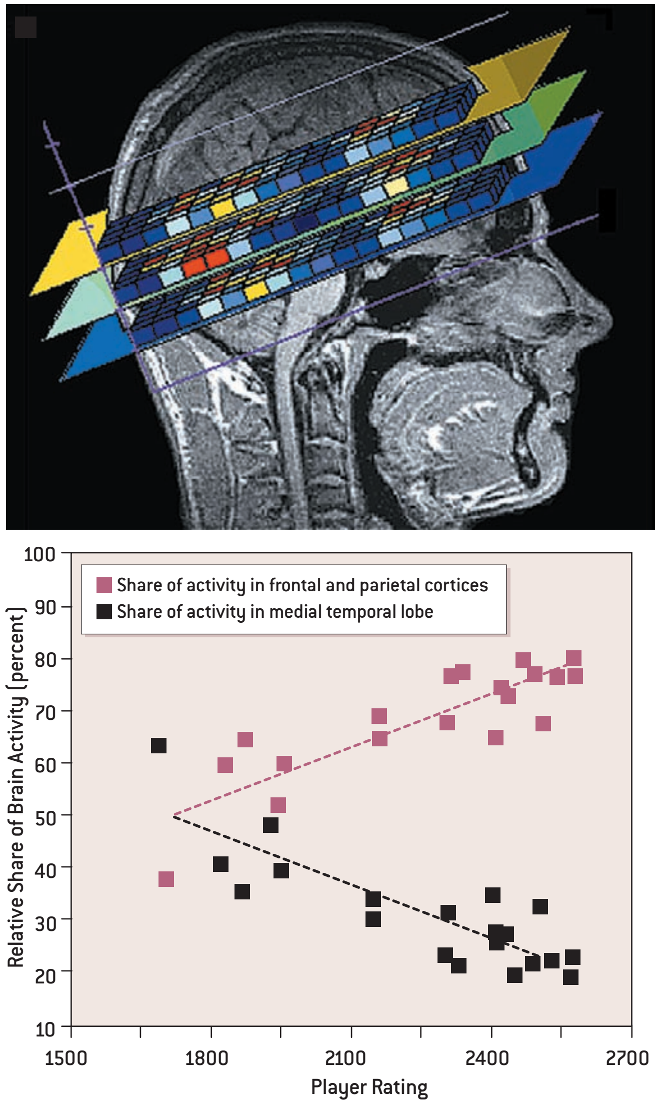


LUCY READING-IKKANDA; SOURCE: "CHUNKING MECHANISMS IN HUMAN LEARNING," BY FERNAND GOBET, PETER C.R. LANE, STEVE CROKER, PETER C.-H. CHENG, GARY JONES, IAIN OLIVER AND JULIAN M. PINE, IN *TRENDS IN COGNITIVE SCIENCES*, VOL. 5, NO. 6; JUNE 2001

thoughts as they examined a position taken from a tournament game. He found that although experts—the class just below master—did analyze considerably more possibilities than the very weak players, there was little further increase in analysis as playing strength rose to the master and grandmaster levels. The better players did not examine more possibilities, only better ones—just as Capablanca had claimed.

Recent research has shown that de Groot's findings reflected in part the nature of his chosen test positions. A position in which extensive, accurate calculation is critical will allow the grandmasters to show their stuff, as it were, and they will then search more deeply along the branching tree of possible moves than the amateur can hope to do. So, too, experienced physicists may on occasion examine more possibilities than physics students do. Yet in both cases, the expert relies not so much on an intrinsically stronger power of analysis as on a store of structured knowledge. When confronted with a difficult position, a weaker player may calculate for half an hour, often looking many moves ahead, yet miss the right continuation, whereas a grandmaster sees the move immediately, without consciously analyzing anything at all.

De Groot also had his subjects examine a position for a



BRAIN ACTIVITY in chess masters is different from the pattern observed in novices. In a 2001 report researchers used magnetoencephalography—the measurement of magnetic fields produced by electric currents in the brain—on subjects playing chess against a computer. In weaker players (*image at top*) more activity occurred in the brain's medial temporal lobe (*left side of colored slices*) than in the frontal and parietal cortices (*right side*), which suggests that the amateurs were analyzing unusual new moves. In grandmasters, however, the frontal and parietal cortices were more active, indicating that they were retrieving information from long-term memory (*data points at right in graph*).

limited period and then try to reconstruct it from memory. Performance at this task tracked game-playing strength all the way from novice to grandmaster. Beginners could not recall more than a very few details of the position, even after having examined it for 30 seconds, whereas grandmasters could usually get it perfectly, even if they had perused it for only a few seconds. This difference tracks a particular form of memory, specific to the kind of chess positions that commonly occur in play. The specific memory must be the result of training, because grandmasters do no better than others in general tests of memory.

Similar results have been demonstrated in bridge players (who can remember cards played in many games), computer programmers (who can reconstruct masses of computer code) and musicians (who can recall long snatches of music). Indeed, such a memory for the subject matter of a particular field is a standard test for the existence of expertise.

The conclusion that experts rely more on structured knowledge than on analysis is supported by a rare case study of an initially weak chess player, identified only by the initials D.H., who over the course of nine years rose to become one of Canada's leading masters by 1987. Neil Charness, professor of psychology at Florida State University, showed that despite the increase in the player's strength, he analyzed chess positions no more extensively than he had earlier, relying instead on a vastly improved knowledge of chess positions and associated strategies.

Chunking Theory

IN THE 1960S Herbert A. Simon and William Chase, both at Carnegie Mellon University, tried to get a better understanding of expert memory by studying its limitations. Picking up where de Groot left off, they asked players of various strengths to reconstruct chess positions that had been artificially devised—that is, with the pieces placed randomly on the board—rather than reached as the result of master play [*see box on preceding page*]. The correlation between game-playing strength and the accuracy of the players' recall was much weaker with the random positions than with the authentic ones.

Chess memory was thus shown to be even more specific than it had seemed, being tuned not merely to the game itself but to typical chess positions. These experiments corroborated earlier studies that had demonstrated convincingly that ability in one area tends not to transfer to another. American psychologist Edward Thorndike first noted this lack of transference over a century ago, when he showed that the study of Latin, for instance, did not improve command of English and that geometric proofs do not teach the use of logic in daily life.

Simon explained the masters' relative weakness in reconstructing artificial chess positions with a model based on meaningful patterns called chunks. He invoked the concept to explain how chess masters can manipulate vast amounts of stored information, a task that would seem to strain the working memory. Psychologist George Miller of Princeton University famously estimated the limits of working memory—the scratch pad of the mind—in a 1956 paper entitled "The Magical Number Seven, Plus or Minus Two." Miller showed that people can contemplate only five to nine items at a time. By packing hierarchies of information into chunks, Simon argued, chess masters could get around this limitation, because by using this method, they could access five to nine chunks rather than the same number of smaller details.

Take the sentence "Mary had a little lamb." The number of information chunks in this sentence depends on one's knowledge of the poem and the English language. For most native speakers of English, the sentence is part of a much larg-

OGNJEN AMIDZIC ET AL. IN *NATURE*, VOL. 412; AUGUST 9, 2001 (*top*); LUCY READING-IKKANDA (*bottom*) er chunk, the familiar poem. For someone who knows English but not the poem, the sentence is a single, self-contained chunk. For someone who has memorized the words but not their meaning, the sentence is five chunks, and it is 18 chunks for someone who knows the letters but not the words.

In the context of chess, the same differences can be seen between novices and grandmasters. To a beginner, a position with 20 chessmen on the board may contain far more than 20 chunks of information, because the pieces can be placed in so many configurations. A grandmaster, however, may see one part of the position as "fianchettoed bishop in the castled kingside," together with a "blockaded king's-Indian-style pawn chain," and thereby cram the entire position into perhaps five or six chunks. By measuring the time it takes to commit a new chunk to memory and the number of hours a player must study chess before reaching grandmaster strength, Simon estimated that a typical grandmaster has access to roughly 50,000 to 100,000 chunks of chess information. A grandmaster can retrieve any of these chunks from memory simply by looking at a chess position, in the same way that most native English speakers can recite the poem "Mary had a little lamb" after hearing just the first few words.

Even so, there were difficulties with chunking theory. It could not fully explain some aspects of memory, such as the ability of experts to perform their feats while being distracted (a favorite tactic in the study of memory). K. Anders Ericsson of Florida State University and Charness argued that there must be some other mechanism that enables experts to employ long-term memory as if it, too, were a scratch pad. Says Ericsson: "The mere demonstration that highly skilled players can play at almost their normal strength under blindfold conditions is almost impossible for chunking theory to explain because you have to know the position, then you have to explore it in your memory." Such manipulation involves changing the stored chunks, at least in some ways, a task that may be likened to reciting "Mary had a little lamb" backward. It can be done, but not easily, and certainly not without many false starts and errors. Yet grandmaster games played quickly and under blindfold conditions tend to be of surprisingly high quality.

Ericsson also cites studies of physicians who clearly put information into long-term memory and take it out again in ways that enable them to make diagnoses. Perhaps Ericsson's most homely example, though, comes from reading. In a 1995 study he and Walter Kintsch of the University of Colorado found that interrupting highly proficient readers hardly slowed their reentry to a text; in the end, they lost only a few seconds. The researchers explained these findings by recourse to a structure they called long-term working memory, an almost oxymoronic coinage because it assigns to long-term memory the one thing that had always been defined as incompatible with it: thinking. But brain-imaging studies done in 2001 at the University of Konstanz in Germany provide support for the theory by showing that expert chess players activate long-term memory much more than novices do [*see illustration on opposite page*].

Fernand Gobet of Brunel University in London champions a rival theory, devised with Simon in the late 1990s. It extends the idea of chunks by invoking highly characteristic and very large patterns consisting of perhaps a dozen chess pieces. Such a template, as they call it, would have a number of slots into which the master could plug such variables as a pawn or a bishop. A template might exist, say, for the concept of "the isolated queen's-pawn position from the Nimzo-Indian Defense," and a master might change a slot by reclassifying it as the same position "minus the dark-squared bishops." To resort again to the poetic analogy, it would be a bit like memorizing a riff on "Mary had a little lamb" by substituting rhyming equivalents at certain slots, such as "Larry" for "Mary," "pool" for "school" and so on. Anyone who knows the original template should be able to fix the altered one in memory in a trice.

The 10-year rule states that it takes approximately a decade of heavy labor to MASTER ANY FIELD.

A Proliferation of Prodigies

THE ONE THING that all expertise theorists agree on is that it takes enormous effort to build these structures in the mind. Simon coined a psychological law of his own, the 10-year rule, which states that it takes approximately a decade of heavy labor to master any field. Even child prodigies, such as Gauss in mathematics, Mozart in music and Bobby Fischer in chess, must have made an equivalent effort, perhaps by starting earlier and working harder than others.

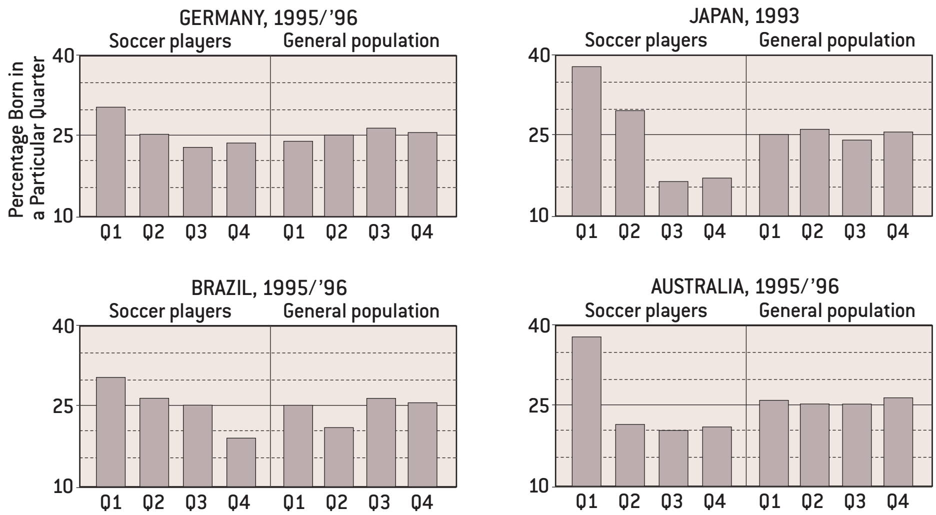
According to this view, the proliferation of chess prodigies in recent years merely reflects the advent of computer-based training methods that let children study far more master games and to play far more frequently against master-strength programs than their forerunners could typically manage. Fischer made a sensation when he achieved the grandmaster title at age 15, in 1958; today's record-holder, Sergey Karjakin of Ukraine, earned it at 12 years, seven months.

Ericsson argues that what matters is not experience per se but "effortful study," which entails continually tackling challenges that lie just beyond one's competence. That is why it is possible for enthusiasts to spend tens of thousands of hours playing chess or golf or a musical instrument without ever advancing beyond the amateur level and why a properly trained student can overtake them in a relatively short time. It is interesting to note that time spent playing chess, even in

TRAINING TRUMPS TALENT

A 1999 study of professional soccer players suggests that they owe their success more to training than to talent. In Germany, Brazil, Japan and Australia, the players were much more likely than average to have been born in the first quarter (Q1) after the cutoff date for youth soccer leagues (*graphs at right*). Because these players were older than their teammates when they joined the leagues, they would have enjoyed advantages in size and strength, allowing them to handle the ball and score more often. Their success in early years would have motivated them to keep improving, thus explaining their disproportionate representation in the professional leagues. Intense motivation and training can also explain the feats of famous child prodigies such as Austrian composer Wolfgang Amadeus Mozart (*left*) and American golfer Tiger Woods (*right*).

NOTE: The cutoff dates were August 1 for Germany, Brazil and Australia, and April 1 for Japan.



tournaments, appears to contribute less than such study to a player's progress; the main training value of such games is to point up weaknesses for future study.

Even the novice engages in effortful study at first, which is why beginners so often improve rapidly in playing golf, say, or in driving a car. But having reached an acceptable performance—for instance, keeping up with one's golf buddies or passing a driver's exam—most people relax. Their performance then becomes automatic and therefore impervious to further improvement. In contrast, experts-in-training keep the lid of their mind's box open all the time, so that they can inspect, criticize and augment its contents and thereby approach the standard set by leaders in their fields.

Meanwhile the standards denoting expertise grow ever more challenging. High school runners manage the four-minute mile; conservatory students play pieces once attempted only by virtuosi. Yet it is chess, again, that offers the most convincing comparison over time. John Nunn, a British mathematician who is also a grandmaster, recently used a computer to help him compare the errors committed in all the games in two international tournaments, one held in 1911, the other in 1993. The modern players played far more accurately. Nunn then examined all the games of one player in 1911 who scored in the middle of the pack and concluded that his rating today would be no better than 2100, hundreds of points below the grandmaster level—"and that was on a good day and with a following wind." The very best old-time masters were considerably stronger but still well below the level of today's leaders.

Then again, Capablanca and his contemporaries had neither computers nor game databases. They had to work things out for themselves, as did Bach, Mozart and Beethoven, and if they fall below today's masters in technique, they tower above them in creative power. The same comparison can be made between Newton and the typical newly minted Ph.D. in physics.

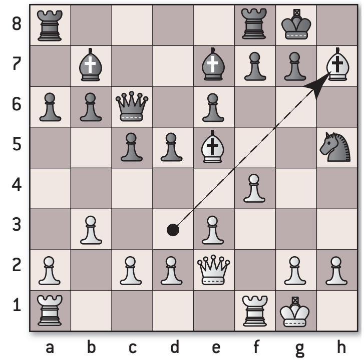
At this point, many skeptics will finally lose patience. Surely, they will say, it takes more to get to Carnegie Hall than practice, practice, practice. Yet this belief in the importance of innate talent, strongest perhaps among the experts themselves and their trainers, is strangely lacking in hard evidence to substantiate it. In 2002 Gobet conducted a study of British chess players ranging from amateurs to grandmasters and found no connection at all between their playing strengths

LUCY READING-IKKANDA; SOURCE: "THE RELATIVE AGE EFFECT IN SOCCER," BY JOCHEN MUSCH AND ROY HAY, IN *SOCIOLOGY OF SPORT JOURNAL*, VOL. 16; 1999 (*graphs*); MOZART MUSEUM, SALZBURG, AUSTRIA/BRIDGEMAN ART LIBRARY (*Mozart*); ALAN LEVENSON *Corbis* (*Woods*) and their visual-spatial abilities, as measured by shape-memory tests. Other researchers have found that the abilities of professional handicappers to predict the results of horse races did not correlate at all with their mathematical abilities.

Although nobody has yet been able to predict who will become a great expert in any field, a notable experiment has shown the possibility of deliberately creating one. László Polgár, an educator in Hungary, homeschooled his three daughters in chess, assigning as much as six hours of work a day, producing one international master and two grandmasters—the strongest chess-playing siblings in history. The youngest Polgár, 30-year-old Judit, is now ranked 14th in the world.

The Polgár experiment proved two things: that grandmasters can be reared and that women can be grandmasters. It is no coincidence that the incidence of chess prodigies multiplied after László Polgár published a book on chess education. The number of musical prodigies underwent a similar increase after Mozart's father did the equivalent two centuries earlier.

Thus, motivation appears to be a more important factor than innate ability in the development of expertise. It is no accident that in music, chess and sports—all domains in which expertise is defined by competitive performance rather than academic credentialing—professionalism has been emerging at ever younger ages, under the ministrations of increasingly dedicated parents and even extended families.



WHITE'S WINNING MOVE is bishop takes pawn on the h7 square. Black's king then captures the bishop, and the white queen captures the black knight at h5, with check, forcing the black king back to g8. White's other bishop then captures the pawn on g7, where it is taken by the black king. The double-bishop sacrifice paves the way for a queen-and-rook attack, forcing black to give up his queen to stave off mate. Emanuel Lasker, the game's winner, went on to become the world chess champion in 1894, a title he retained for 27 years before losing to José Raúl Capablanca.

The preponderance of psychological evidence indicates that experts are made, not born. What is more, the demonstrated ability to turn a child quickly into an expert—in chess, music and a host of other subjects—sets a clear challenge before the schools. Can educators find ways to encourage students to engage in the kind of effortful study that will improve their reading and math skills? Roland G. Fryer, Jr., an economist at Harvard University, has experimented with offering monetary rewards to motivate students in underperforming schools in New York City and Dallas. In one ongoing program in New York, for example, teachers test the students every three weeks and award small amounts—on the order of \$10 or \$20—to those who score well. The early results have been promising. Instead of perpetually pondering the question, "Why can't Johnny read?" perhaps educators should ask, "Why should there be anything in the world he can't learn to do?" SA

The preponderance of psychological evidence indicates that EXPERTS ARE MADE, NOT BORN.

Furthermore, success builds on success, because each accomplishment can strengthen a child's motivation. A 1999 study of professional soccer players from several countries showed that they were much more likely than the general population to have been born at a time of year that would have dictated their enrollment in youth soccer leagues at ages older than the average [*see box on opposite page*]. In their early years, these children would have enjoyed a substantial advantage in size and strength when playing soccer with their teammates. Because the larger, more agile children would get more opportunities to handle the ball, they would score more often, and their success at the game would motivate them to become even better.

Teachers in sports, music and other fields tend to believe that talent matters and that they know it when they see it. In fact, they appear to be confusing ability with precocity. There is usually no way to tell, from a recital alone, whether a young violinist's extraordinary performance stems from innate ability or from years of Suzuki-style training. Capablanca, regarded to this day as the greatest "natural" chess player, boasted that he never studied the game. In fact, he flunked out of Columbia University in part because he spent so much time playing chess. His famously quick apprehension was a product of all his training, not a substitute for it.

LUCY READING-IKKANDA

Philip E. Ross, a contributing editor at Scientific American, *is a chess player himself and father of Laura Ross, a master who outranks him by 199 points.*

MORE TO EXPLORE

The Rating of Chessplayers, Past and Present. Arpad E. Elo. Arco Publishing, 1978.

Thought and Choice in Chess. Adriaan de Groot. Mouton de Gruyter, 1978.

Expert Performance in Sports: Advances in Research on Sport Expertise. Edited by Janet L. Starkes and K. Anders Ericsson. Human Kinetics, 2003.

Moves in Mind: The Psychology of Board Games. Fernand Gobet, Alex de Voogt and Jean Retschitzki. Psychology Press, 2004.

The Cambridge Handbook of Expertise and Expert Performance. Edited by K. Anders Ericsson, Paul J. Feltovich, Robert R. Hoffman and Neil Charness. Cambridge University Press, 2006.