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Chapter Four
Expertise as Process

Everyone learns, more or less continuously throughout the waking hours of their lives. Yet not everyone becomes an expert. It has been shown that even the factory worker whose job consists of pulling down the handle on a drill press becomes increasingly proficient at this task, year after year. And surely the children sometimes labeled 'non-learners' in school are learning something during their hours at the desk, although perhaps not what was intended or not at the expected rate.

There are several commonsense ways of explaining how it is that everyone learns but not everyone becomes an expert. One way is to attribute the differences to native ability or to quality of training, opportunities for experience, and the like. Another is to say that everyone does become expert at something, except that only certain kinds of skill and knowledge are

publicly credited as expertise. These are defensible points, but of a kind that tends to stifle thought. They tell us that there is nothing further to be found out about expertise; expertise is just learning accompanied by other factors of aptitude, opportunity, or social approval.

Our whole approach to expertise centers on the idea that there is more to it than these commonsense views suggest. We believe there is something experts do over and above ordinary learning, which accounts for how they become experts and for how they remain experts, rather than settling into a rut of routine performance. The preceding chapter has anticipated what this special something is that experts do: They solve problems. But everyone solves problems, too; and if we take the rather expansive definition of problem solving that is current among cognitive scientists, people are engaged in problem solving much of the time. In this chapter we shall try to show what is distinctive about the problem solving experts do. The distinction is not in how they tackle a given problem, which is what most research on expert problem solving has investigated. Such research shows, as previously noted, that experts tackle problems more efficiently, making use of their superior knowledge. That almost goes without saying. Of considerably more significance is *the kinds of problems experts tackle*. Experts, we propose, tackle problems that increase their expertise, whereas nonexperts tend to tackle problems for which they do not have to extend themselves.

Expert and Nonexpert Skill Development

To illustrate the general idea, we will start with a comparison of two elementary school teachers. School teaching is an especially good area for bringing out distinctions between expert and nonexpert skill development. Any school teacher who survives for long has necessarily developed a high level of skill in certain aspects of the teaching craft, yet it is widely accepted that a large proportion of school teachers are not expert.

Margot and Cynthia are similar in many respects. They both have been elementary teachers for almost two decades. Both are easy-going, relaxed to the point of being slow-moving, firm but patient and warm with their pupils. If you walk into either classroom you are likely to find all the children pleasantly busy. Principals and supervisors regard both of them as excellent teachers. This only goes to show how misleading appearances can be when it comes to judging teaching, however.

In Margot's classes, reading problems are few and most of the children read well beyond their expected levels. The children are equally at home with numbers, and they often do amazing things in writing and in science, showing sophisticated levels of knowledge and thinking. Although Cynthia's pupils come from much the same social environment as Margot's, many of them have learning problems in reading or mathematics. Mathematics achievement is generally low, writing tends to be legible but drab, and science is not taught at all.

In the early days of their careers, we imagine, there would not have been much observable difference between the two teachers. Both would have been mainly concerned with management, getting their classrooms to run in a peaceful and comfortable way. But as management problems diminished, Margot began turning her attention to problems of learning. Two decades later, she is still advancing—not with great speed, but with considerable cumulative effect. She does not simply try out new ideas. In fact, she is skeptical of most innovations. However, she is sensitive to children's shortcomings in learning—to the things they fail to understand, to the challenges they tend to dodge—and to teaching activities that don't seem to have produced the results she expected. So she is continually experimenting and refining. When she takes up a new idea from elsewhere, she plans carefully how to harmonize it with her teaching, so as not to undo what she has already accomplished. It is not just sensed inadequacies that keep her advancing. These have diminished over the years, and the main stimulus for advancement now is that she keeps discovering new potentialities in the children. Recently, for instance, she

has become more aware of children's potential to help one another, and she is cultivating this potential with her characteristic patience and thoughtfulness.

Cynthia, by contrast, has developed into what is referred to by some waggish critics as a 'fanny teacher.' The progress of her skill in managing a classroom could be charted by the increasing proportion of time she spends sitting behind her desk instead of on her feet tending to things. Her pupils spend a good portion of the day doing exercises in workbooks. Cooperative learning in Cynthia's classroom means that she benignly ignores children copying from others, so long as they do it quietly. She eliminated science because it was too messy and difficult to control. She is not idle at her desk. Children bring work to her to be checked, and she coaches those who are on the wrong track. There are always problems arising in a classroom full of young children, but Cynthia has developed reliable ways of dealing with them, ways which characteristically begin with, 'Robert, come up here, please.'

Both teachers are very skillful at what they are trying to do, and so it is tempting to say that both are experts, but with different specializations. Besides compunctions one might have about calling someone an expert whose skill is in avoiding the work she is being paid for, there is a more fundamental reason for not lumping Margot and Cynthia together as experts in the same sense. It has to do with the process they have gone through in becoming what they are. Both of them, we assume, started out with difficult problems to solve. Every school teacher does. Imagine these problems as items on a very long list, with problems at the top having priority. Cynthia's and Margot's lists were initially much the same, let us assume, with the top problems perhaps being those of sheer survival as a teacher. As problems are eliminated, they get checked off. In a profession like teaching, eliminating a problem does not mean it is gone forever. It means that you have a fairly reliable way of dealing with it when it recurs. What Cynthia did, as the top problems were checked off, was move farther down the list, with the eventual goal of eliminating all of them. She is almost there. Only very rarely is the placid routine of her classroom

disturbed by an event or condition for which she does not already have a routine response.

Margot, too, has over the years been eliminating problems from her list. She, too, has developed effective routines for preventing or dealing with many kinds of difficulties. To this extent, her progress has been the same as Cynthia's. The difference is that, as problems are eliminated from the list, Margot adds new ones at the top. The problems at the top of her list now are problems she could not even have formulated early in her career. They have to do with distinctions she was not then aware of, such as the distinction between children's telling what they know and explaining what they know. Also, perennial problems, such as children weak in self-esteem or overly demanding of help—problems that she once dealt with in simplistic ways—now appear in much more complex formulations on her list. In fact, most of the problems on her original list have not actually been eliminated but have been replaced by new versions that reflect her increasing wisdom.

To generalize, Cynthia's story represents the normal kind of learning that everyone experiences as they adapt to an environment. Things that were initially difficult become easier. Things that called for problem-solving effort come to be handled by well-learned routines. Things that required deliberate attention and thought come to be second nature. This kind of learning is universal. It distinguishes old-timers from beginners, but it does not distinguish experts from experienced nonexperts.

Margot's story also reflects normal learning, of course, but it shows in addition two things that we believe constitute the process of expertise. These are *reinvestment* and *progressive problem solving*. In the normal course of learning, as problem-solving effort is taken over by well-learned routines, fewer mental resources are needed to accomplish the same results. For Cynthia, the result is a continual decrease in the amount of activity, mental and physical, that her work requires. The problem solving she does do is aimed at eliminating still more problems, thus reducing activity even further. For Margot, however, the result of normal learning is that she has mental resources available to reinvest in the advancement of her

teaching, in the pursuit of new goals or of goals that she did not previously have the resources to pursue. Furthermore, Margot recognizes that there are constitutive problems of her profession that are not eliminated by having a routine way of handling them. These are problems such as maximizing children's learning, helping them realize their full potential, enhancing the quality of their school experience. No matter how effective one may be as a teacher, there is always a higher formulation of these problems that represents a challenge not yet met. This continual reformulation of problems at higher levels, as lower levels are achieved, is what we mean by progressive problem solving.

Reinvestment and progressive problem solving are not separate processes. They are two aspects of the same process, which is what we are calling the *process of expertise*. Reinvestment is the motivational aspect. It is not just willingness to exert effort. There are plenty of teachers who pursue their work more energetically than Margot, responding to the countless demands for their attention, many of which Margot ignores or treats casually. Reinvestment involves both conserving resources, so as to have something to reinvest, and putting those resources back into the activity itself rather than dissipating them or directing them elsewhere. Progressive problem solving is the cognitive aspect of the process of expertise. It is generally not enough just to try to do better. What was learned last time must somehow be translated into a better articulation of the goal or problem so that the next effort will be better conceived. We shall say more in later sections about what progressive problem solving consists of.

Some Psychological Background

The ideas of reinvestment of mental resources and progressive problem solving are built upon some more general concepts that are well known in cognitive psychology but that are somewhat different from their counterparts in everyday psychologizing. Some familiarity with these more general concepts will be helpful in following the discussion in this and later chapters.

Problem Solving

Problem solving has a much broader meaning in contemporary cognitive psychology than it does in ordinary usage. Ordinarily we think of a problem as something being wrong that needs correction or else as a puzzle put to us as a challenge. As the term is currently used in cognitive psychology, however, a problem exists whenever there is a goal which we do not already have a known way of achieving. If you are driving to some out-of-the-way place for the first time, you have a problem. You don't already know a route and will have to find one. The problem may prove quite easy. A few minutes studying a road map may suffice. But you don't know this for certain. There may turn out to be complexities. For instance, there may be no direct route and you will then have to calculate various distances, also taking into account what you can discern about the nature of the roads and the number of towns they pass through. Then it may occur to you that some routes are likely to be more scenic than others, or that one route passes near a cheese factory said to have marvellous cheddar, thus opening the possibility of achieving multiple goals on the trip.

Broadly speaking, any nonroutine purposeful activity is a problem in the sense we are using the term. Buying someone a present is a problem, unless you do it in a completely formulaic way. Arranging flowers in a vase is a problem. So is writing a story or deciding how to spend a day off, but probably not taking out the garbage or paying a restaurant bill with a credit card. Problem solving can be pleasant or unpleasant, creative or mundane. All that is required to constitute problem solving is some amount of searching or deliberation in order to find a way to achieve a goal. So when we talk about the process of expertise as involving progressive problem solving, one must not get the idea that this means going at some grave predicament with knotted brow. We might be talking about progressive problem solving applied to flower arrangement.

The difficulty of problem solving depends on the constraints that are to be honored. Constraints, too, is a very general notion and does not necessarily mean something unpleasant. In fact, pleasantness itself may be a constraint involved in such

problems as choosing a place to dine or writing a message on a greeting card. All the same, constraints add to the difficulty and complexity of problems. Choosing a restaurant is much easier if you do not include a constraint that the food must be interesting; it may become extremely difficult if you add constraints so that, in addition to providing interesting fare, the restaurant must be inexpensive, close by, and quiet.

Complexity is a matter of the number of constraints that must be taken into account at the same time in problem solving. It does not take much for a problem to become too complex to cope with. If you have ever tried, as we have recently, to design a house renovation that meets the intricate constraints of municipal building codes, you know what it is to be overwhelmed by complexity. It seems that whatever you do to meet one constraint violates another. You believe there must be a solution, but finding it seems to demand keeping all the constraints in mind at once—the constraints imposed by the building codes, by your own vision, by your budget, and by the laws of nature—and this proves impossible.

Mental Resources

One of the central ideas of modern cognitive psychology is the limited processing capacity of the cognitive system. For present purposes, what this may be taken to mean is that a normal adult can only keep on the order of four things actively in mind at the same time. What accounts for this bottleneck in our mental processes is not settled, and so we use the noncommittal term, "mental resources," to refer to whatever it is that limits the size of mental task we can handle. A great deal of mental activity is not resource-demanding, meaning that it has little or no effect on the resources available for thinking. Subjectively, it is experienced as activity that does not require conscious attention, that we can perform while thinking about something else. For skilled typists, typing is not resource-demanding, and so they can devote all their mental resources to thinking of what to write. For less skilled typists it does demand some resources, and this interferes with their composing, because they must divide resources between the two tasks. Consequently, they will

prefer to write their first drafts longhand, because handwriting is normally not resource-demanding.

Mental resource limitations explain why we are so easily overwhelmed by problem complexity. If a problem can be broken down into steps so that we have to deal with only a couple of constraints at each step, we can handle it. Try multiplying a pair of three digit numbers mentally and you are likely to fail, because you need to keep partial products in mind and remember where you are in the problem, and that is likely to stretch mental resources beyond limit. The paper-and-pencil algorithm you learned at school makes the task manageable because at each step you have to remember only two digits and perhaps a carry, write down the result and forget about it while you move on to the next step.

Most real-world problems are not reducible to step-by-step economizing of mental resources. Take the design of a building renovation referred to earlier. It may help to list all the relevant building code rules and the various other criteria and constraints on a sheet of paper, but there they all are—dozens of them, perhaps—and you have to come up with a design that meets them all simultaneously. How is a poor four-constraint mind supposed to cope? There is little chance that the idea you come up with, which meets the four constraints you happen to be holding in mind, will fortuitously meet the remaining twenty.

Herbert Simon observed that most real-world problems are of the building renovation variety. They are too complex for us to deal with all the constraints in any rational fashion. He coined the term 'bounded rationality' to describe what we do instead. We create a simplified mental representation of the problem and solve it rationally.[1] An obvious simplification of the house renovation problem is to delete all the design ideas that appear to conflict with building codes. This reduces the number of constraints, although it results in a design that is not the design of our dreams but something simpler and more conventional. An even more radical simplification of the problem is to change it from 'design a renovation' to 'engage an architect to produce the design of our dreams'. Now, from the

home-owner's point of view, the design process has been reduced to a step-wise procedure: Express your ideas to the architect. When the architect produces a provisional design, discuss changes to bring it closer to your wishes. The architect produces a second draft, and the procedure repeats until something is settled. Of course, in this case the complexity of the design problem remains, but it has been off-loaded onto the architect. How it is that the architect can handle design problems of a much greater complexity than we can is the question to be addressed in the next section. It is obviously a question of significance for understanding expertise.

Circumventing Mental Resource Limitations

Given that mental resource limitations are more or less the same for everyone, how is it that some people can handle much more complex problems than others? Why is the architect able to take our specifications and produce a design that meets them and the building codes as well, whereas our minds are boggled by the number of constraints that must be taken into account? More remarkable, perhaps, is the performance of the building plan inspector at City Hall. Although exhibiting no other signs of superior intelligence, he glances at one complicated drawing and says, 'That driveway's too wide', glances at another and remarks, 'Lord only knows what's supposed to hold this staircase up'. Such performance seems to defy normal resource limitations and thus immediately suggests expertise. Indeed, one definition of expertise, proposed by Timothy Salthouse, is "the process or processes of circumventing normal human limitations on human information processing."[2]

For reasons to be explained later, we do not accept this as a sufficient definition, but it certainly points to something of prime importance in the development of expertise, and that is acquiring the ability to deal with greater complexity within one's domain. There is no known way of producing a general increase in a person's information-processing capacity. Whatever apparent gains are achieved must be due to learning ways of making more effective use of a fixed capacity.[3] There are a number of ways that this is done, but we will discuss only two of the most general ones, *pattern learning* and *procedural learning*.

Understanding of the human mind has profited greatly from having something relevant to compare it to, namely, the intelligent machine. Computers have their limitations, but they are not the same ones we have. Holding a number of things in mind at once is not the problem for a computer that it is for us.

Consequently computers are much better than we are at carrying out long chains of reasoning or tracing many different inferential paths to find the one that reaches a goal. That is how computers manage to play chess better than most people. This also means that computers are much better than we are at assessing the combined effect of a number of variables, as must often be done in making predictions or diagnoses. On such tasks, relatively simple statistical operations carried out by computer regularly outperform human experts.[4] For instance, if you want to screen job applications, you are better off feeding the available data into a computer program than handing it to a personnel expert. Although personnel experts may be better than other people at integrating the variety of information contained in a personnel file, they are still not very good compared to a computer, which can process a large number of variables in combination.

As John Anderson has pointed out, however, there are two kinds of processes that human beings are able to carry out much better than today's intelligent machines: pattern recognition and procedural learning. Anderson suggests that the development of expertise is not just a matter of getting better at doing things. It involves changing the way we do them, so that instead of relying on processes that we are inherently poor at, we are able to accomplish tasks through use of the processes we are inherently good at.[5] Novices in a domain have to do a lot of figuring things out, which means relying on their very limited ability to hold constraints in mind and consider numbers of variables in combination. Old-timers in a domain have

managed to shift most of the burden on to pattern recognition and learned procedures. which are not hampered by the same mental resource limitations.

Pattern learning. While it has been a challenge to get computers to recognize 26 letters of the alphabet in handwritten form, young children find the irregularities of handwritten forms hardly any obstacle. We are very good at recognizing recurrent patterns despite local variations. The fifty thousand chessboard patterns attributed to the chess master may sound awesome, but an educated adult easily recognizes that many different words, and that is pattern recognition too. What matters most, however, is not the number of patterns learned but the proportion of cases they cover. Skilled internists may or may not recognize fifty thousand disease symptom patterns, but expert diagnosticians commonly report that they recognize enough to cover about 95 percent of the cases they see. Beginning internists will recognize far fewer and so will have to do a great deal more problem solving. At least we hope that is what beginning internists will do. Another possibility, which is discussed further in Chapter 6, is that they will rely on the limited number of symptom patterns they have learned and thus will misrecognize a number of diseases.

How the mind recognizes and uses patterns is only beginning to be understood.[6] Learning patterns is not enough; the right ones need to be recalled at the right time, which is also something that people are much better at than computers. An important part of pattern recognition is recognizing when no available pattern fits—recognizing that the person at the door is a stranger or that the pattern of symptoms is inconsistent with the diseases you are familiar with. For our present discussion, however, the essential point is that pattern recognition processes occur without effort. They do not use up mental resources, and so to the extent that the world we are dealing with consists of familiar patterns, our minds are free for other uses.

Procedural learning. The gain to mental economy that comes from having well-learned procedures was extolled by William James, who referred to it as "habit."[7] Perhaps the most familiar example from modern times is automobile driving—a complicated procedure, which at first takes all one's mental resources and yet eventually takes hardly any at all, enabling some people to transact business by telephone while driving through traffic.

John Anderson's theory of skill acquisition, referred to in the preceding chapter, is currently the most complete theory of how procedural learning works. Anderson's theory links up nicely to ideas about expertise. Skill learning, according to Anderson, starts out as problem solving. The beginning driver is solving dozens of problems, and sometimes having to deal with several at once, such as down-shifting and turning a corner. That is why the demand on mental resources is so great. The learner solves these problems, drawing on remembered facts and rules and piecing together already-available skills. As the same problems recur, however, the learner can begin relying on memory for how they were handled before. Two things start to happen. Procedures that at first must be called up separately, such as *hold down the clutch, grasp the gear lever, move the gear lever up and to the right,* become chunked into a single procedure, such as *shift to third gear.* Also, facts or rules that previously had to be remembered and applied, such as *when turning left onto a two-lane thoroughfare, turn into the inner lane and then cross to the outer lane,* become incorporated into the procedure and no longer need to be considered. Thus, once the correct way of turning onto a two-lane thoroughfare has become habitual, the driver may no longer even be aware that it involves entering one lane and then crossing to another.

These processes of proceduralization continue until the originally problem-fraught activity becomes, as is said, 'automatic'. Automaticity is the great freer of mental resources, but it is obtained at a cost. The cost is loss of conscious access. It becomes difficult to modify a well practiced procedure. Many people, for instance, have not learned the approved way of making a left turn onto a two-lane thoroughfare, and the longer they have been driving the harder it is to get them to change. We should not exaggerate this drawback, however. Automaticity

suggests machine-like regularity and inflexibility. Automaticity of human skills is seldom like that at all. The driver whose mind is on a telephone conversation is not driving like an automaton but is making all kinds of flexible adaptations of speed and direction. The inflexible driver is the beginner or the infrequent driver whose skills are not so finely attuned to conditions. Where automaticity is a handicap is not in performance but in the *improvement* of performance. That is why it is problematic in the development of expertise.

The proposed answer, then, to how the architect and the building plans inspector are able to accomplish things that overtax our own mental resources is that they are the beneficiaries of pattern learning and proceduralization. Whereas to us every design configuration is new and requires thought, for them many configurations are familiar and immediately recognizable as legal, illegal, or problematic. This is no more effortful for them than recognizing faces on the street as friends, strangers, or people we want to avoid. They have probably also developed fairly automatic routines for going about the tasks of design or plan inspection, so that the procedures themselves do not require much in the way of resources. This does not mean that the architect produces routine or unimaginative plans. It may mean just the opposite, that by being spared the use of mental resources for coping with mundane problems of code compliance and structural integrity, the architect has resources free to devote to imaginative construction. However, it *could* mean that the architect's plans have become as routine as the procedures that produce them, just as the plan inspector's judgments may become so dominated by learned patterns that anything that does not fit a familiar pattern is judged to be illegal or a mistake.

That is why we cannot go along with Salthouse or Anderson in equating pattern learning and proceduralization with the development of expertise. These processes characterize all learning. They belong as much to the experienced nonexpert as to the expert. Keep at an activity long enough and the patterns and procedures will form themselves. They may be good ones, they may be bad ones, but they will be patterns and

chunked procedures of some sort. This is the normal course of learning. Consequently, *if we are to discover anything distinctive about expertise as a process, it must consist of something that goes on over and above this normal course of learning.*

Expertise as Reinvestment: Going Beyond Normal Learning

Accident statistics suggest that it takes two years of driving before skills have developed to the point where people cease to be menaces on the highway. It takes that much learning, evidently, before enough patterns and skilled procedures have been acquired that a driver will automatically do the right thing at the right time and will have enough mental resources available to exercise intelligent judgment when it is required. Most people reach this state of skill, yet few would be counted expert drivers. A course in defensive driving will reveal just how limited the average driver's skills are and how inadequate they are for almost any kind of driving emergency.

Driving thus provides a commonplace illustration of the fact that normal learning is not enough to produce expertise. Although driving skills probably continue to improve indefinitely with experience, in the sense of becoming increasingly smooth and automatic, they do not rise above a level of mediocrity. It is not that we reach the limits of our capacity. With training we could become much better. Rather, it seems that our skills develop up to the level that is required for the environment we drive in and no higher. Some driving environments, such as southern Europe, are more demanding than others, such as rural America, and so people's skills will taper off at different levels, and a change of environment may reopen skill learning. But the essential fact remains the same: Normal learning leads to 'satisficing', as Herbert Simon put it—to performance that is 'good enough' but not to expertise.

The difference between normal learning and the learning that leads to expertise can be traced to what we do with the mental resources that are set free by normal learning. Driving,

as we have noted, places heavy resource demands on the beginner's mental resources, but these demands diminish greatly with practice. What do drivers do with these freed-up mental resources? Listen to the radio, talk on the telephone, plan ahead, daydream—all manner of things, which are alike only in that they have nothing to do with driving.

But suppose your ambition is to be a racing car driver. The same sort of normal learning occurs. Initially demanding tasks become automatic, freeing up mental resources. But instead of using these resources for unrelated purposes, you apply them to improving your driving performance. Thus mental resources, as they become available, are reinvested in the activity, leading to further growth in skills and knowledge. This, we propose, is the process by which people move beyond the plateaus of normal learning and acquire expertise.

Now, one might ask, isn't this simply normal learning shifted to a different environment—the environment of the racetrack? This is a question of great significance for understanding expertise, because it brings us to identifying the kind of environment that fosters expertise.

Our answer to the question is both yes and no. Yes, the racetrack is a different environment and the racing car driver's learning can be attributed to adaptation to that environment. But, no, learning to be a racing car driver is not simply normal learning in a higher gear, so to speak. If the racetrack were merely an environment in which one must adapt to very fast-moving traffic, then learning to become a racing car driver would not differ in any essential way from learning to become an ordinary highway driver. Learning would still taper off at a level that was sufficient for getting along in the environment. But a racetrack is not just a highway with very fast-moving traffic. It is a track where drivers race, which means that everyone is trying to get to the finish line ahead of everyone else. Consequently, there is no 'good enough' level at which the race driver's skills can level off. Skills that are good enough to win this year will not be good enough next year, because other drivers will have been working to improve (and engineers and mechanics will have been working to improve the cars, which

is a different story with the same plot). The racing car driver is adapting to an environment that is continually changing in ways that require still higher levels of learning. Thus there is not the normal leveling off.

We will say more in a later section about environments that foster expertise. Competitive environments are only one kind. At present, however, we want to focus on the individual and to consider the various ways that mental resources may be reinvested so as to develop expertise. The following are common forms of reinvestment:

1. **Reinvestment in learning.** The endless practicing that athletes and performing artists do represents reinvestment of this kind. So is the time that professionals put into keeping up with the journals in their field and attending training workshops in new procedures. There seem to be few professions any more where the daily practice of the profession itself provides sufficient learning experience. It is necessary also to put effort into learning itself. Before we got involved in technology projects, we had naively assumed that computer programming was one occupation in which, after some initial training, people learned entirely by doing. But it turns out that expert programmers are voracious consumers of computer literature, readers of bulletin boards, and seekers of advanced training. In general, learning has turned out to be so vital a part of expertise that it warrants examination as an aspect of expertise in its own right, which is how it will be treated in Chapter 6.

2. **Seeking out more difficult problems.** For athletes and hobbyists this is a common recourse whenever normal learning threatens to reduce life to a routine: Move up to a stiffer level of competition, climb a steeper mountain, build a more complicated birdhouse. Such moves do not just require trying harder. They confront one with problems that cannot be handled by applying previously learned procedures. There are opponents with

new tricks; there are new obstacles or constraints. To succeed, new knowledge has to be brought into use, new skills developed, or old skills applied in different ways. Thus using spare mental capacity to tackle more difficult problems produces the kind of learning we associate with expertise. In many occupations, however, seeking out more difficult problems requires a change of job or even a change of specialization, and so it is not a continuously available outlet for surplus mental resources.

3. Tackling more complex representations of recurrent problems. This is the most interesting of the ways of reinvesting mental resources, and the one most central to the process of expertise. Earlier we mentioned Herbert Simon's idea of bounded rationality—the idea that, because of mental resource limitations, we are obliged to work with simplified versions of real-world problems, the actual problem situations being too complex for us to handle. This being the case, then as resources are made available through normal learning, it should be possible to work with less simplified representations of problems. That is what Margot, the more expert of the two teachers described earlier, seems to have done. Each year, with a new class of students, many of the same problems present themselves as in years before. But they are not the same problems to Margot. For instance, a recurrent problem for primary grade teachers is the child who is having trouble with reading and who is showing emotional problems as well. A helpful school psychologist can usually be relied upon to provide a dossier indicating the child has a conglomeration of cognitive deficits, unfortunate home conditions, social maladjustments, a history of possibly damaging illnesses, and so on. We have seen dossiers that went into a grandmother's drinking problem, even though the grandmother had only incidental contact with the child. With so much hard-to-assimilate information, rationality must be bounded indeed. Early in her career, Margot's representation of such a case might have been: *a child with multiple problems of a serious kind requiring professional help.* With that simplified representation, a solution is not hard to find—a solution, that is, which would take responsibility off Margot's shoulders and put it on to the shoulders of specialists. Later in her career, however, when Margot was no longer overwhelmed by the problems of managing a classroom, she might have represented the problem in a way that took account of the child's particular anxieties, including his anxieties about her. With this more complex representation, she would have tried to work out a solution in which she played a role as someone who could do something about the child's anxieties, feelings of failure, and so on. As for the child's reading difficulties, however, her representation might still have been very simplified. For instance: *a child who has a history of failure experiences with reading.* This representation would have suggested solutions along the lines of making reading tasks easier for the child. Such a solution would work well in some cases and badly in others.

In later years, Margot might produce a yet more complex representation of the problem, which takes account of the fact that the child's reading difficulty and anxiety have reciprocal effects on one another, so that an adequate solution will have to deal with both factors at once. This would still be a simplification of the actual state of affairs. One does not escape from bounded rationality. But it would be a substantial advance over the earlier representations. The point we are trying to make is not simply that as Margot becomes wiser she represents problems more intelligently. That may be true, but even if Margot knew as much about reading problems ten years ago as she knows now, she might not have been able to put that knowledge to use because her repertoire of learned patterns and procedures was too limited to provide her with means of bringing the more complex version of the problem within the limits of her mental resources.

Earlier, *child with reading problem* and *child anxious about performance* might have been two separate patterns, giving rise to two factors that would need to be held in mind in working toward a solution. Later, *child afraid to guess at words* might have been learned as an immediately recognizable pattern. This one pattern incorporates elements of the other two and adds something more. It becomes a useful token that can be moved about along with several others on the mental checkerboard in order to solve a problem that would earlier have required too many tokens.

Progressive Problem Solving

Margot's progress in dealing with more and more of the complexity of the same basic problem is an example of *progressive problem solving*. The premise is that the complexity was there from the beginning. She is not making a simple problem more complex. In fact, it is through the simplifications provided by pattern and procedure learning that she is able to keep advancing in dealing with the essential complexities of the problem.

Environmental concerns are adding to the complexity of a great range of problems. Every large building project is rendered more complex because of the need to consider environmental impact. Manufacturing, waste disposal, transportation —all these present more complex problems to engineers and designers than they did in the days before environmental awareness. But the complexities have been there right along, it is just that they were not recognized or attended to. Of course, much of what we know today about the environmental effects of things like fluorocarbons and acid emissions was not known in years back, so it is not simply a matter of people's ignoring the facts. Looking at it more positively, the effect of progressive problem solving is not only to advance in dealing with the complexities already known to exist but also to expand knowledge in ways that bring more complexities to light. Some of these may be complexities created by previous attempts at solution (side-effects of drugs, for instance), but others have always been there (such as the extraordinary complexity of

nutrition, where one compound influences the body's utilization of another).

Not all problems are endlessly complex. If they were, we would not be able to gain the benefits from pattern recognition and proceduralization that make it possible for us to keep advancing on those problems that are. If arithmetic were endlessly complex, no one would ever make it to algebra. But there is a certain class of problems that are endlessly complex, where progressive problem solving never approaches an endpoint, and these problems have a special relevance to expertise. We shall call these *constitutive problems of a domain*. A constitutive problem of teaching is the elimination of ignorance. There is obviously no end to this problem, but progress is possible, and expertise in teaching entails making such progress. Similarly, a constitutive problem of medicine is the elimination of disease, a constitutive problem of social planning is the elimination of misery, a constitutive problem of negotiation is an agreement in which all parties consider themselves winners, and a constitutive problem of baseball pitching is to get all batters to strike out, ground out, or fly out.

Professions and other expert domains are in an important sense defined by their constitutive problems. Change the constitutive problem and you change the profession in a fundamental way. That may be happening in medicine, with movements to change the constitutive problem from the elimination of disease to the achievement of health for everyone. The idea of constitutive problems helps us to deal with issues such as whether Margot and Cynthia are both experts but with different skills. We can argue that Cynthia does not engage in the process of expertise, that her skills in classroom management, impressive as they may be, are a result of normal learning and do not involve reinvestment of mental resources into the activity. But one could imagine a teacher who does reinvest mental resources into the task of minimizing teaching. One of us knew a college instructor who made an art out of this, who in essence persisted in working toward the ideal of reducing to zero the amount of thought and effort he put into teaching. He scheduled all his classes at 7 a.m., he said, so that his work day would be over before he was fully awake. One

might with justice call such a person an expert, but not an expert teacher. He kept reinvesting mental resources into progressive problem solving, but the problem he invested them in is not a constitutive problem of the teaching profession.

By handling some aspects of a problem more or less automatically, the skilled person has mental resources to spare for paying attention to other aspects of the problem that previously had to be ignored. The physician may go on treating the same illnesses, but can pay attention to a greater range of symptoms and complicating conditions. The small contractor may go on doing kitchen renovations, but can work them out within a larger context of possibilities, paying attention to more constraints, taking more account of clients' preferences and needs. Domains in which expertise can flourish are domains in which there is no inherent limit on progress. There is always a larger context within which the present problem-solving effort is partial and oversimplified.

To the extent that people engage in progressive problem solving they work at the edge of their competence. Studying string quartets, sociologists Murnighan and Conlon remarked of the more successful ones: "The fact that they never quite achieve their ultimate goal—to produce transcendent, glorious sound that is just beyond their reach—keeps them continuously striving to achieve it."[8] Working at the edge of competence is risky and taxing, but it yields two great benefits. It results in superior accomplishments: More being ventured, more is sometimes gained. And it leads to further growth as competence advances. New or redesigned skills are acquired, beyond those developed through normal processes of learning. Moreover, the new skills are not simply added like new books to a library. They combine with the old skills to form superskills, which make it possible to progress toward still more complex problems calling for still more complex skills, and so on. That, in essence, is the process of expertise.

Progressive Problem Solving versus Problem Reduction

The opposite of expertise is normally thought of as incompetence, bungling, doing things the hard way. Those are

appropriate contrasts when we are considering expertise from the standpoint of performance. When we consider it from the standpoint of process, however, the opposite of expertise is the opposite of progressive problem solving. That is something we may call *problem reduction*.

Problem reduction reflects the commonplace view of problems as things to be gotten rid of, to be *reduced* in number and severity. It also represents a common way in which problems are handled, by *reducing* them to tasks that can be handled with routine procedures. Thus, much of normal learning and adaptation can be put under the heading of problem reduction. Starting out on a job or an enterprise, we expect to encounter a host of problems. Little by little, we expect those problems to diminish, to be solved and eliminated. New problems crop up, of course, but we expect a net decline in the problem-solving load. Prospects would be very discouraging otherwise. Problem reduction occurs in two ways. Some problems, once solved, stay solved. Installing a new piece of equipment and getting it to run is an example. Other problems recur, but we develop routine ways of handling them. In effect, they cease to be problems and become merely tasks.

The ideal toward which problem-reduction efforts strive is a condition where there are no more real problems, where everything that comes along can be handled with existing procedures. Although such an ideal is obviously unattainable, it nevertheless provides useful direction. It encourages planfulness and a search for lasting rather than stop-gap solutions.

Problem reduction sounds so good, in fact, that it sounds like just another word for intelligence. Bhaskar, Herstein, and Hayes go so far as to calibrate expertise according to the proportion of cases likely to be encountered that are already covered by existing knowledge.[9] They see the growth of expert knowledge as an unending but nevertheless diminishing process. The reason is that one first learns to handle the most frequently occurring problems. As time goes on, one develops knowledge of increasingly rare cases, so that there is no end to learning, but the amount of problem solving one has to do gets closer and closer to zero.

Thus Bhaskar, Herstein, and Hayes's analysis would suggest that problem reduction and progressive problem solving are one and the same, whereas we are making them out to be opposites. The seeming contradiction is easily resolved, however. It is no doubt generally true that, with increasing experience, experts less and less often encounter unfamiliar cases; but that is also true of the experienced nonexpert. Thus Bhaskar, Herstein, and Hayes are not really distinguishing expertise. Differences between experts and experienced nonexperts would show up primarily in *how* they deal with unfamiliar cases. To what extent do they try to construct new concepts and methods for unfamiliar cases, as compared to force-fitting them to existing routines? To what extent do they redefine familiar problems at higher levels, so as to take more inherent complexity into account? To what extent do they put more effort into the more difficult cases?

Problem reduction is intelligent behavior. Most of us practice it in most areas of our lives and should probably do more of it. Only in that way can we gain enough time and resources to pursue progressive problem solving where it counts. Paying bills, getting to and from work, keeping an orderly home and workplace—these are all activities that one hopes to reduce to the point where they cease to be problems. To pursue expertise in all areas of our lives would be both suicidal and impractical. The process of expertise is the opposite of problem reduction, but it depends on problem reduction.

One has to know where to pursue problem reduction and where to pursue progressive problem solving. Problem reduction with respect to the core problems of one's career means becoming the equivalent of a 'fanny teacher'. Problem reduction in the area of family life means sterile marriages, neglected children. Problem reduction in one's personal development may mean becoming one-dimensional. In its fullest sense, progressive problem solving means living an increasingly rich life—richer in that more and more of what the world has to offer is taken into one's mental life. But that increasing richness, because of its time and cognitive demands, requires the judicious reduction of peripheral problems. Sages like Henry David Thoreau have been telling us that for a long time.

What Motivates the Process?

In discussing progressive problem solving and how it works to keep expertise developing and to prevent settling into ruts, we have been discussing the cognitive side of the process of expertise. But there is also a motivational side, identified with the continuing reinvestment of mental resources. By definition this takes effort. 'Investing mental resources' is another way of saying 'exerting mental effort'. It implies 'paying attention to', 'thinking about', or 'trying to achieve' something. The effort is not necessarily intense. Margot, the teacher we have been using as an exemplar, is not a high-pressure person by any means. Still, she is continually tackling problems at levels that extend her, even though her skills are good enough that she could function adequately as a teacher by staying comfortably within what she already knows how to do. If we are to understand expertise, we must not only understand what experts do that is special but also why they do it.

Cognitive psychologists are often accused of ignoring motivation. A more generous appraisal would be that they honor the principle that if you don't have something worthwhile to contribute on a topic you should refrain from speaking. Most of what psychologists of any sort have to say about motivation is warmed-over common sense. The part that is not common sense involves the brain, but it is at such a basic level that we cannot expect it to be helpful in distinguishing experts from experienced nonexperts. There are, however, three ideas that seem worth highlighting because of their special relevance to the process of expertise. The first is the idea of 'flow', which suggests that one of the reasons people are willing to put effort into the process of expertise is that it actually *feels* good. The second is the idea of 'second-order environment', which are social environments that, unlike most social environments,

provide support for the process of expertise. The third is the idea that there is a heroic element in expertise. This last is not an explanation of why people put effort into the process of expertise, but rather an acknowledgement that the other explanations do not quite do the whole job.

Flow

The term *flow* was coined by Mihaly Csikszentmihalyi to refer to an experience of sustained pleasure that he found to be reported by artists of all kinds, athletes, scientists, mountain climbers, and many others, when they were absorbed in an activity that sounds to us very much like the process of expertise. These people in diverse walks of life, said Csikszentmihalyi, "when they describe how it feels when they are doing something that is worth doing for its own sake, use terms that are interchangeable in their minutest detail."[10] Prominent among characteristics of the flow experience are total absorption in the activity, a feeling of being in control, and a loss of self-consciousness, which Csikszentmihalyi attributes to all mental resources being invested in the activity, so that none are available for self-reflection. Also attributable to the total investment of resources in the activity are escape from the concerns of daily life and loss of normal time monitoring, so that minutes may seem like hours or hours may seem like minutes.

So pleasurable is it to be 'in flow' that people who experience it want to keep experiencing it, but this requires what amounts to progressive problem solving. Flow, according to Csikszentmihalyi, requires a nice balance between ability and challenge. If challenge exceeds ability, the result is anxiety and frustration rather than flow. If ability exceeds challenge, the result is boredom. Combined with the inevitable effects of learning, this means that repetition of the same activity will eventually cease to produce the flow experience. It will get too easy. Something must be done to increase the level of challenge so as to bring it into harmony with the increasing level of ability. Thus there is a progressive element inherent in the quest for the flow experience. As Csikszentmihalyi puts it,

> To remain in flow, one must increase the complexity of the activity by developing new skills and taking on new challenges. This holds just as true for enjoying business, for playing the piano, or for enjoying one's marriage, as for the game of tennis. Heraclitus's dictum about not being able to step in the same stream twice holds especially true for flow. This inner dynamic of the optimal experience is what drives the self to higher and higher levels of complexity. It is because of this spiraling complexity that people describe flow as a process of 'discovering something new', whether they are shepherds telling how they enjoy caring for their flocks, mothers telling how they enjoy playing with their children, or artists describing the enjoyment of painting. Flow forces people to stretch themselves, to always take on another challenge, to improve on their abilities.[11]

What Csikszentmihalyi appears to be describing is exactly the same process that we have been talking about as the process of expertise, except that he is describing its subjective aspect. We arrive at the same point, from different starting places. We started with cognitive behavior, asking, 'What do experts *do* that distinguishes them from experienced nonexperts?' Having identified the process of reinvesting mental resources in progressive problem solving, we then ask why people do it, and are led to intrinsic pleasure as one explanation. Csikszentmihalyi started with the motivational question. Having identified flow as a motivator of exceptional performance, he then asked what is required to produce this experience, and was led to an idea of progressive challenge that is the subjective counterpart of the process of expertise, this same reinvestment of mental resources into tackling things at higher levels of complexity.

If the process of expertise is so addictively enjoyable, however, why doesn't everyone practice it and thus become an expert? One answer is that flow is much harder to achieve in some situations than others. As Richard Mitchell puts it, "Flow emerges in circumstances that are perceived as both problematic and soluble."[12] In many highly routinized jobs it is difficult to perceive problems. The problems may have to be invented.

Typists working in typing pools have been observed to invent little games and challenges to keep life interesting. Larry Hirschhorn has studied work situations in which people perceive problems as insoluble. There, as Csikszentmihalyi has hypothesized, anxiety is the dominant experience. It occurs with nurses working in wards for terminally ill patients, with executives in enterprises that are failing or out of control, and with nuclear power plant technicians overwhelmed by complexity and sense of risk. The common response that Hirschhorn has observed is for people in such situations to "retreat within the boundaries of their roles."[13] They do their jobs in ways that minimize challenges—the very opposite of the process of expertise. If it worked, this strategy might nevertheless result in flow experience, by bringing challenge down to a level commensurate with ability. But instead the strategy leads to worsening of conditions, increased anxiety, and thus to further retreat.

There appear also to be individual differences in how disposed people are to seek or create flow-inducing levels of challenge. Csikszentmihalyi, studying mathematically talented high school students, found some who were typically bored while others typically enjoyed themselves in doing the same homework. It wasn't that the bored ones were more talented and thus found the homework less challenging, Csikszentmihalyi claims, but rather that the unbored students were able to find challenging aspects in the work that the bored students were not. In Chapter 6, dealing with what we call 'expertlike learners', we will look further into this ability to bring the process of expertise into learning situations.

Expert Subcultures as Second-Order Environments

Experts seldom exist in isolation. Often they are linked together by associations or informal networks, but even when that is not the case they are connected through a tradition in which expertise evolves over generations as well as within the careers of individuals. We may therefore speak of a subculture of expertise existing in a field. This subculture embodies ideals and goals that direct the process of expert development. It provides help and cooperation leading to success, as well as

forms of recognition of success—recognition that people outside the subculture would be unable to give. (We think, for instance, of jazz musicians, most of whom play for little money to naive audiences, but who are sustained by a subculture that provides highly sophisticated mutual admiration.) The subculture provides models of expert careers so that novices have a better idea of where their efforts are taking them.

In most social environments, adaptation is adequately served by normal learning of the kind we described earlier. The newcomer suffers from lack of requisite knowledge, skills, and customs, yet as these lacks are remedied through experience in the environment, life becomes less problematic and learning tapers off. But in an expert subculture, one of the requirements of adaptation is to participate in the pursuit of ideal goals of the group, and this necessitates continued progressive problem solving. Adapting to a scientific subculture, for instance, requires more than mastering a body of scientific knowledge and skills. One is expected to make some advance on an unsolved problem between this year's convention and the next. Or if it is an artistic subculture, one is expected to have made some contribution to the cumulative tradition of the art. In nonexpert environments, the process of expertise is deviant. Within an expert subculture, however, progressive problem solving and continued building of competence are not deviant but instead are central to one's participation in the life of the expert community. An expert community, we might say, is one in which to conform is to grow (although to grow is not necessarily to conform).

The distinction we are trying to make here needs to be put at a more general level. For it is not simply that experts inhabit one kind of social environment and nonexperts another. Experts are found in all kinds of environments, only some environments are supportive of the process of expertise and others are inhospitable. And there are supportive environments in which not everyone is an expert.

We may call the ordinary situations of work and everyday life *first-order environments*. They present a relatively fixed set of conditions, and learning tapers off as one adapts to

those conditions. Problems occur, of course. In fact, some first-order environments may be crisis-ridden. But in first-order environments problems occur as aberrations that need to be removed. Public transportation systems, custodial institutions, and insurance agencies are common examples of this kind of environment.

Second-order environments are ones in which the conditions to which people must adapt change progressively as a result of the successes of other people in the environment. Every social environment changes, and in retrospect historians may discern pattern in the change, but there is no inner logic, no entelechy. But within the world of auto racing, for instance, there is. Each team's advance in technology or strategy sets a new standard which others try to surpass, with the net result that, except for periodic changes in regulations, lap speeds keep going up and up. Adapting in the world of racing means adapting to a progressive set of conditions. Competition is not the only dynamic force, although it is seldom wholly absent in expert domains. In science, conditions keep changing as a result of continual contributions to knowledge.

The crucial point is that in second-order environments one does not merely adapt to continual change. That is true of first-order environments as well, to the extent that they are unstable. One adapts to changes that keep raising the ante, by setting a higher standard of performance, by reformulating problems at more complex levels, or by increasing the amount of knowledge that is presupposed. Through adapting, one raises the ante for others, and so on. Thus there is a compounding of achievements, much like the compounding of capital by investment. It occurs within the individual career, but it also occurs at the level of the community. Consequently, second-order environments override the rigidifying effects of habit and practice, by progressively altering the conditions to which individuals in the environment must adapt.

An important limitation of expert subcultures is that one typically has to possess some level of expertise already, in order to gain admittance to them. Thus they are good for sustaining and elevating expertise, but not for fostering its early development. In Chapter 7 we will discuss the possibility of turning schools into second-order environments, which they decidedly are not at the present time. Then in Chapter 8 we will consider the idea of a whole society that functions as a second-order environment, so that expertise and its process become normal rather than exceptional.

The Heroic Element in Expertise

People in second-order environments may pursue progressive problem solving merely as a way of conforming. But experts can be found in first-order environments as well. They may be rare, but they exist. They can be found here and there behind shop counters, at government office desks, driving taxis, installing telephones, or at home caring for children. They reinvest mental resources in their work, elevating it or expanding its scope to take in a broader set of concerns—such as the concerns of their clients. They exhibit professionalism in its favorable sense, but without benefit of professional identification or a professional subculture to support them. The intrinsic rewards of flow might partly explain what motivates them, but the nature of their work suggests that they must often pursue an expert course with flow experiences being few and far between. In such cases, pursuing high standards and continuing to advance requires an element of heroism. And we mean heroism literally, in the sense of arduous efforts that benefit society but that are disproportionate to what society provides in the way of rewards and supports.

Heroic expertise is especially to be found in occupations where one person's work does not impinge on or serve as a model for another's. Mail delivery is an example. Letter carriers go off on their respective routes, and if one of them does a particularly good or poor job this has little effect on the others and may not even be known to them. The same is true of school teachers, working away in separate classrooms. In such occupations there is often an official ethos of heroic type: the image of the letter carrier braving storm and flood to deliver the mail,

and of the teacher selflessly devoted to nurturing the young mind. The images reinforce the fact that the hero must go it alone; there are few social forces lending support.

Even within expert subcultures, however, there is a heroic aspect to exceptional expertise—the individual, striving ahead beyond the supports of kin and community, pursuing some lonely ideal of excellence or knowledge. When Charlie Chaplin said, "I'm not a genius, I'm just a perfectionist", he was being modest about his talents but at the same time he was subtly laying claim to heroic status. He was suggesting that his many-faceted art, which admirers attributed to natural genius, was instead the result of pursuing fine points of excellence which the public could not recognize, let alone support.

Athletes and performing artists often convey the heroic image by virtue of the arduous training and drill that they sustain. While the rest of us shuffle through life they are off somewhere sweating to bring their performance up to that moment which we will ignorantly applaud as a display of natural talent. Similarly, there are the scientists working their 60- or 80- hour weeks pursuing, not personal excellence, but an advance in knowledge that most of the world is in no position to care about.

The heroic aspect does tend to get overblown, however, partly because it is the superstars who have biographies written about them, and heroic effort is often part of their story. Undoubtedly the numbers are much larger of people in various walks of life who qualify as experts and who invest substantial effort in the processes that have developed their expertise, but whose efforts are comfortably attuned to life's rewards. The process of expertise may involve continual investment in progressive problem solving, as we propose, but it does not follow that the effort must be arduous. There are all kinds of experts. Some have so much talent that progressive problem solving comes easily to them. Others may pursue their careers along lines of least resistance, yet do so in a line that nevertheless leads upward to increasingly complex problems. The issue in distinguishing expert from nonexpert development is not the intensity of effort, although that may count greatly in determining how far people go and at what speed; rather, as we have emphasized, it is a matter of what the effort is invested in.

Even with the most laid-back and convivial of experts—like the teacher, Margot—it seems that there must be some element of heroism. For if expertise involves progressive problem solving and progressive problem solving entails working at the edge of one's competence, then at least a bit of daring is inevitably required. It is always tempting to stay with tasks that fall comfortably within one's competence. Working at the edge risks failure and loss of esteem (especially in professions where the expert image is of always knowing the right answer). But it also provides a certain excitement, which is probably addictive.

How Experts Stay Out of Ruts

The normal learning that makes expertise possible also endangers it. Pattern learning and procedural learning free mental resources so that they are available for reinvestment but at the same time they build up bodies of pattern knowledge and habits which, with continuing practice, become increasingly difficult to modify. This suggests that experts, through the very practice that makes them skillful, may be deepening a rut that will eventually entrap them.

There is a real-life problem here, not just a theoretical conundrum. People do get into ruts. Experts past their prime come to be labeled as 'deadwood' or as members of an 'old guard', resistant to new ways of doing things. But even if rigidification is inevitable, it is somehow staved off to a remarkable degree and often over long spans of years in the careers of many experts. Rigidity, indeed, is the mark of the failed expert. But explaining why experts don't get caught in their own ruts does present a puzzle, somewhat like the puzzle of why spiders don't get caught in their own webs.

When we have posed this problem to psychology students, their commonest answer is that experts are favored with a trait of flexibility. There may indeed be such a trait, perhaps even

at the neural level, but there is no evidence or reason to suppose that experts have more of it than other people. Or even if they do, we still have to explain why, with increasing expertise, it does not become more and more difficult to adapt flexibly.

Rather than looking for something special in the make-up of experts, we do better to look for something in the process of expertise itself that keeps it from rigidifying. Getting out and tackling new problems has a rejuvenating effect. That much has been demonstrated in many ways through work with the elderly. Old people who have started to shut down and vegetate can change dramatically by getting re-engaged in problem solving of almost any sort. From work with monkeys (who show similar effects of aging), there is evidence that the effects are physiological, not just psychological. Hormone levels and sperm counts rise. The biological clock truly gets set back.[14]

Problem solving, it appears, is good for your health. There are dramatic data showing how closely longevity is related to occupational level. This holds even with the civil service, where all enjoy incomes adequate to meet physical needs and work under similar physical conditions. Careful analyses have indicated that the effect has much to do with autonomy and power. High-level managers, despite working under more stress, markedly outlive civil servants in lower-echelon jobs and indeed show less evidence of stress-related symptoms.[15] One of the things autonomy gives is ability to set the level at which one addresses problems, so that there is an appropriate match of problem complexity to ability to deal with that complexity. Flow experience may be only the more dramatic manifestation of a generally healthier state of affairs that occurs when this match is achieved. The alternatives—boredom if complexity is too low, anxiety and frustration if it is too high—are likely among other things to lead to rigidity and getting into a rut.

The puzzle of why automaticity does not inevitably lead to rigidity disappears if we think of automated skills as building blocks of new skills that are not automated. The experienced chess player learns many patterns. But for the expert these do not become patterns that restrict thinking and result in stereotyped, predictable play. Instead, they are used as building blocks for increasingly sophisticated analyses and strategies of play.

Similarly, the experienced writer learns to recognize many familiar rhetorical patterns—ways of organizing, of putting across points, of making transitions. These *could* be used to produce facile, unoriginal, and tiresome prose, which is what hack writers do. But expert writers are always constructing more challenging writing problems for themselves, both at the level of larger purposes and at the sentence-to-sentence level. In trying to do justice to their content, they raise more difficult writing problems for themselves, and in trying to produce a good piece of writing, they raise problems that force themselves to reconsider content. Thus writing becomes a process of discovery in which knowledge is transformed through the writing process and the writing itself ends up developing in ways they could not have anticipated.[16] It is the inexpert writers who get into ruts, whose writing is predictable and often much like that of their peers. We know of writing teachers who forbid their students to write science fiction, because they cannot stand the sameness of it—story after story patterned after whatever televised science fiction series happens to be popular at the time. For inexpert writers learned patterns direct performance. For more expert writers learned patterns provide a kind of vocabulary out of which to produce original constructions.

One often hears it suggested that knowing too much is dangerous because it provides prepackaged ways of thinking and acting and thus stands in the way of fresh ideas and new ways of seeing things. We will examine this notion a little more closely in the next chapter, in discussing creative expertise. But as an explanation for why people get into ruts, this notion is useless. Having a repertoire of learned patterns and procedures is not what causes people to get into ruts. Given enough experience, everybody acquires the repertoire. What gets people into ruts is reducing problems to levels that can be

handled by those learned patterns and procedures. The antidote to this is progressive problem solving. Getting into a rut is proof that you are not carrying on the process of expertise.

Broader Implications of the Process View

Engaging in the process of expertise by no means guarantees expertise that will be recognized in the world at large. That may additionally require special talents and opportunities. It also, of course, requires a society prepared to recognize one's accomplishments. Expert moose callers will go unheralded in most parts of the world. And a common reaction to new movements in art has been to judge the practitioners as lacking in skill. To what extent the process of expertise is *necessary* for achieving recognized expert status is an open question. Evidence linking the process to experts is mostly anecdotal or based on samples too small for generalizing to whole populations. It seems a fair guess, however, that in many fields the category of recognized experts will include some who were so talented that they achieved expert status without putting effort into progressive problem solving and perhaps others whose superior training enables them to function on a par with those more fully engaged in the process of expertise.

If the process of expertise is neither necessary nor sufficient to achieve what is generally recognized as expert status, then why make so much of it? An analogy may serve in place of a full response: Aerobic exercise is a process that has been found to play a significant and many-faceted role in health, yet it is obviously not sufficient to ensure good health and it is not necessary, either, as demonstrated by the existence of people who enjoy good health despite total abstinence from aerobic exercise. For most favorable states of affairs in the world it is impossible to specify necessary and sufficient conditions. Rather, one looks for things that make a difference and that it is possible to do something about. Heredity probably has more to do with health than exercise ever could, but we cannot do anything about our heredity, whereas we can do something

about exercise. Similarly, it may be that, at least in some fields, native talent has more to do with determining who will achieve an expert level of performance than does any process potentially under the control of the learner. But that does not detract from the value of examining processes.

Pursuing the analogy a little further, aerobic exercise and related ideas of fitness have contributed to changing the concept of health. The claim that there are healthy people who do not get aerobic exercise, and that therefore aerobic exercise is not necessary for health, starts to be weakened because we begin to have doubts about calling people healthy just because they are free of disease. Similarly, we believe that with advances in understanding the process of expertise, the concept of expertise will begin to be altered and sharpened so that it picks out something that is more clearly distinguishable from talent, routine skill, and advantages of training.

A refined concept of expertise would not only exclude some of what was previously in, but would include some of what was previously out. The implications in this direction are more interesting and promising. There are areas where it seems profitable to think in terms of a process of expertise, but where conventional notions of expertise do not apply. Examples of such areas are childhood, the handicapped, groups, and society.

Early Forms of Expertise

Although it may take years to achieve expert levels of performance, the process of expertise could in principle begin very early. Therefore, instead of looking only for potential or precursors of expertise in children and beginners, we could look for the real thing—that is, for evidences of reinvesting mental resources in progressive problem solving—and could try to support those early manifestations of the process of expertise.

Although people who work with children seldom apply notions of expertise, cognitive-developmental theories provide ideas that come close to defining a process of expertise. Piaget offered a very general conception of intelligence as the complexity of "the pathways between the subject and the objects on which it acts."[17] In his well-known stage theory of development,

each stage represents a more complexly structured interaction between person and environment. Whereas Piaget dealt with the logical structure of stages, neo-Piagetians such as Pascual-Leone, Case, Fischer, and Siegler have formalized and extended the idea of growth in complexity and have been able to apply it to growth within particular domains of skill. Case has mapped developmental sequences according to the number of task or problem constraints that people are able to incorporate into an action plan. There is an increase within developmental stages in the number of constraints that can be handled and transition to a higher stage occurs when constraints that had previously been handled singly are chunked into larger structures that can be handled as single units, thus making possible a major advance in the complexity of mental tasks that can be managed. Intellectual growth according to such a scheme is essentially identical to what we describe as the process of expertise—growth that consists of addressing problems at increasingly complex levels, taking advantage of pattern learning and automaticity to free up mental resources that can be applied to taking more problem variables into account.[18]

Lev Vygotsky, a psychologist whose brief but illustrious career in the early years of the USSR has lately begun to influence developmental and educational psychologists worldwide, provides another perspective on child development that fits well with a process of expertise. The relevance of Vygotsky's ideas can be conveyed most directly if we translate them immediately into terms of expertise: Expertise, Vygotsky might have said, exists already in the culture. The learner's first contact with it comes through participating in activities along with people who already have the expertise (helping mother bake a cake, for instance). Gradually more responsibility is handed over to the learner, and in the process the learner 'internalizes' the expertise.[19] Vygotsky could be said to describe a process of expertise that is not carried on by the child alone—at least not at first—but that rather is carried on by child and parent acting jointly. Research by Benjamin Bloom and his students on the early beginnings of outstanding achievement in fields like music and sport indicates that such joint participation of parent and child in what amounts to progressive problem solving is vital for getting the child off to the early start that is necessary in such fields. In Chapter 6 we will explore in more detail the process of expertise among learners.

Expert Process without Expert Performance

The fact that the process of expertise need not necessarily result in what is socially recognized as expert performance has a positive side to it. It means that the benefits of pursuing this process can be experienced by people who have no prospect of achieving expert status. This is already obvious in the realm of amateur sport. One does not have to be an internationally ranked tennis professional to enjoy the flow experience that comes from being totally into one's game. All that is required, besides the right disposition, is to be matched with opponents at the right level, so that one is challenged but not badly overmatched. Amateur sport is generally organized so as to make this possible, and thus to provide possibilities for continual reinvestment and progress for that huge majority of people who have no prospect whatever of becoming world class athletes. Sports for handicapped people provide a particularly heartening example, one that has been handled so successfully that people who excel in some categories of 'special olympics' sports do in fact gain public recognition as experts.

There are other areas of life where the same principle could apply but usually does not. The wheelchair-bound people who learn to play competitive basketball get recognition and support, we suggest, not because the public recognizes the arduous process they have gone through to attain such skill but because their performance exceeds that of most people who are not wheelchair-bound. But what about the more severely handicapped person whose achievement is limited to navigating in a motorized wheelchair or to speaking just articulately enough to carry on a conversation with tolerant listeners—in short, someone whose visible achievement in no way exceeds the general norm? The *process* by which these seemingly

limited achievements were made may have been just as expert-like as that of the wheelchair basketball star or the world-class tennis player.

This is not simply a matter of getting credit for trying. The world is not very generous in giving such credit in any circumstance. The practical point is that there are many areas of human endeavor where the process of expertise could produce significant gains for people, but where the process needs fostering and encouragement. Overcoming reading handicaps is an example. Although reading is a very complex skill, it is easily mastered by most people and so the ability to read a magazine article at the rate of a few hundred words a minute and understand it gains no recognition as expertise. But for some substantial minority of people—perhaps 10 or 15 percent of students undergoing conventional instruction in North America—such an achievement is problematic and likely never to be realized. Such people are categorized as learning disabled. The ordinary ways of dealing with them are as far as one could imagine from supporting a process of expertise. They are regarded as people with ailments that need to be diagnosed and treated. They may be coddled and given unchallenging tasks or they may be subjected to a regimen of exercises intended to improve their brains, but in any event they are shielded from any suggestion that there are problems to be solved and that they might be the ones to solve them. Although some may be helped in reading (the effectiveness of most treatments is abysmally low) nothing is done to provide them with either the motivation or the knowledge that would enable them to go on in an expertlike manner addressing problems of reading at progressively higher levels of complexity. With adults receiving treatment for reading problems, in fact, there are indications that they become so dependent on the therapist that they are sometimes reluctant to learn to read and thereby end the relationship.

Yet reading disabilities typically present conditions that are classic for the process of expertise. Poor readers, experiments have shown, have to invest more mental resources than good readers do in just figuring out what the words are. Consequently they have fewer resources available for understanding what they read. If they are to progress they need not only to build up efficient pattern recognition and procedures so as to free more mental resources, but they also need to reinvest those resources effectively back into the task of reading. We at one time worked with a child who exhibited the classical symptoms, but who was otherwise a bright child who took an expertlike approach to intellectual tasks as long as they did not involve reading. Clare Brett, who worked most directly with him, essentially instituted a process of progressive problem solving in which both of them participated, with increasing amounts of the initiative being turned over to the child. He began doing his own analyses of what he was doing in reading and devising strategies for doing it better. Not only did his reading skills improve to above-average levels, but he was able to go on improving on his own, despite being in a learning disabilities class where all his earlier, self-defeating strategies were reinforced. (Backsliding is a well-recognized problem in all kinds of educational remediation with children.) He soon earned release from the learning disabilities class and has been doing well since in regular classrooms. To our minds, this is an instance of someone becoming an expert—a competent performer in an area that does not require a process of expertise for most people but that did for him. In this case the child already had some expertlike dispositions to build on. However, Valerie Anderson has been helping teachers to take this same basic approach—getting the student as well as the teacher engaged in progressive problem solving—and impressive results are being obtained even with very low-achieving students who show no signs of expertise in any academic area.[20]

Once the process of expertise is unhinged from the idea of expert status, we can probably discover many other areas where the process would be worth trying to understand and to support. Some of these will be discussed in the final chapter, on prospects for an expert society.

Expertise not Confined to the Individual

When we view expertise as a process, there is no *a priori* reason for stipulating that the process must go on within an individual

mind. One kind of joint process of expertise has already been mentioned—the kind that involves an adult and a child, where the child is not yet competent to carry on the process single-handedly, but can do so with an adult, who may gradually turn initiative over to the child. Other instances involve groups that function as units: sports teams, surgical teams, teams of air traffic controllers, and so on. Studies of such groups indicate that they show many of the same processes as individuals. They learn, solve problems, get into ruts, get out of ruts, display expertlike or nonexpertlike characteristics.

Viewing groups in terms of expert or nonexpert processes is a sharp departure from the way that has become entrenched in Western thinking since the Industrial Revolution. Industrial rationality called for a view of people working together as consisting of discrete individuals each performing a specified function—the gears in a machine metaphor. The industrial process depended on how skillfully and reliably the individual functions were performed. That proved to be a powerful notion, and it has spread to military and athletic organizations as well. The 'team player' is often thought of as one who unstintingly performs his or her designated function without trying to go beyond it.

Expert teams, or 'high-performance' teams as they are called by people who study them, turn out to be quite different from this. Although there may be assigned jobs, everyone on the team knows more or less how to do everything and thus they are able to trade off functions in a highly flexible manner as events require. The group progressively develops ways as a unit to achieve higher goals or to achieve goals more successfully. Thus it makes sense to speak of a single process of expertise that is carried out by the team functioning as a unit. The expert team does not just do its work well, it *gets somewhere*. This is obvious in a scientific research team. It has a trajectory much like that of an individual research career except that it involves a group, whose membership may change from time to time even though the process remains coherent and continuous. The same is true of musical groups and improvisational comedy groups.

There have also been studies of groups that we see as following a nonexpert course of development. Deborah Gladstein studied sales teams and found a number that got on very well together, where problems were few and agitations minimal, and where everyone felt that things were going nicely—except that in comparison to other groups they weren't selling much. These would seem to be groups that followed the course of problem reduction, evolving routines that made life increasingly pleasant and effortless but at the expense of no longer addressing the problems that constituted their reason for being in the first place.[31]

At still higher levels of aggregation, we can imagine whole societies that could be characterized by expert or nonexpert processes. Even though the members would not be functioning in the coherent manner of a team, and so there would be no entity that you could call an expert, there may be much to gain by considering the social process as a whole from the standpoint of how surplus mental resources are invested, to what extent they are reinvested in progressive problem solving as against being dissipated in other ways. This is an idea we will explore in the final chapter.

Summary

In the normal process of becoming good at something, operations that once took thought and planning come to be done with little or no mental effort. Situations that once had to be analyzed come to be recognized instantly and effortlessly, like a familiar face. Behavior that once had to be thought through step by step becomes organized into efficient packets, nicely suited to the situations that call for action. Formal knowledge comes to be incorporated into the procedures themselves and no longer needs to be recalled. Actions become increasingly streamlined and precisely adapted to circumstances.

This normal process of learning is the foundation of expertise, but it is not what makes expertise distinctive. Expertise is distinguished by what people do over and above this normal

process. While the normal process leads to efficiency, it also leads to rigidity and to a tapering off of learning as it reaches a level that suffices for ordinary needs.

In domains where expertise flourishes, problems tend not to have ceilings on them. There is always a higher level at which a problem can be approached, taking more variables into account, reaching a higher standard of result, or meeting a larger and more subtle range of requirements. The process of expertise is the process of tackling problems at higher and higher levels—what we refer to here as 'progressive problem solving'. This process builds on normal learning, because it is through normal pattern learning and proceduralization that mental resources become freed to reinvest in these higher-level efforts. But by continually incorporating already-mastered skills into more advanced procedures, the expert avoids the rut that normal learning can produce. The process is greatly aided by expert subcultures, where individual advances have a cumulative effect, progressively changing the conditions that members of the subculture adapt to. There remains, however, a heroic element to exceptional expertise, for it involves effort over and above what the surrounding society recognizes or rewards.

Chapter Four: Expertise As Process

1. Simon 1957, 198.
2. Salthouse 1991.
3. There is a claim that has been passed around for years in self-improvement circles, that we normally use only 10 percent of our mental capacity. Having heard it so many times, people are inclined to believe there must be some basis for it, but as far as we have been able to make out, there is none, and it isn't even clear what the claim means. The point that this pseudo-fact is usually enlisted to support, however, is not far off from the one we are making here: that it is possible through learning to make much more effective use of the capacity given us by nature.
4. Camerer and Johnson 1991.
5. Anderson 1985.
6. The most promising work has used computer models that at some level simulate the nervous system rather than simulating rational behavior. These have proved more adept and humanlike in their ability to recognize patterns in the environment and to adapt behavior to them (McClelland et al 1986; Beer 1991).
7. James 1914.
8. Murnighan and Conlon 1991.
9. Bhaskar et al. 1983.
10. Csikszentmihalyi and Csikszentmihalyi 1988, 29.
11. Csikszentmihalyi and Csikszentmihalyi 1988, 30.
12. Mitchell 1988, 36.
13. Hirschhorn 1988.
14. Suomi 1991.
15. Marmot 1986.
16. Bereiter and Scardamalia 1987b; Scardamalia and Bereiter 1991b.
17. Piaget 1960, 10.
18. Case 1985. Various neo-Piagetian theories are presented in Siegler 1978.
19. Vygotsky 1978; Wertsch 1985.
20. For a general treatment of reading ability from a cognitive point of view, see Perfetti 1985 or Stanovich and Richardson 1991. The poverty of the diagnostic-remedial approach is documented by Arter and Jenkins (1979). Dependency in adult nonreaders is reported by Johnston (1985). Our analysis of reading difficulties is presented in Bereiter 1988 and Brett and Bereiter 1989, the latter also containing a detailed report of the case summarized here. Valerie Anderson's work is reported in Anderson and Burtis (in press).
21. Gladstein 1984.

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