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Recognizing, Defining, and Representing Problems

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What are the problems that you are currently trying to solve in your life? Most of us have problems that have been posed to us (e.g., assignments from our supervisors). But we also recognize problems on our own (e.g., you might have noticed the need for additional parking space in the city where you work). After identifying the existence of a problem, we must define its scope and goals. The problem of parking space is often seen as a need for more parking lots or parking garages. However, in order to solve this problem creatively, it may be useful to turn it around and redefine it as a problem of too many vehicles requiring a space in which to sit during the workday. In that case, you may be prompted to redefine the problem: You decide to organize a carpool among people who use downtown parking lots and institute a daytime local taxi service using these privately owned vehicles. Thus, you solve the problem not as you originally posed it but as you later reconceived it.

Problem solving does not usually begin with a clear statement of the problem; rather, most problems must be identified in the environment; then they must be defined and represented mentally. The focus of this chapter is on these early stages of problem solving: problem recognition, problem definition, and problem representation.

THE PROBLEM-SOLVING CYCLE

Psychologists have described the problem-solving process in terms of a cycle (Bransford & Stein, 1993; Hayes, 1989; Sternberg, 1986). The cycle consists of the following stages in which the problem solver must:

1. Recognize or identify the problem.
2. Define and represent the problem mentally.
3. Develop a solution strategy.
4. Organize his or her knowledge about the problem.

5. Allocate mental and physical resources for solving the problem.
6. Monitor his or her progress toward the goal.
7. Evaluate the solution for accuracy.

The cycle is descriptive, and does not imply that all problem solving proceeds sequentially through all stages in this order. Rather, successful problem solvers are those who are flexible. The steps are referred to as forming a cycle because, once they are completed, they usually give rise to a new problem, and then the steps need to be repeated. For example, if you solve the parking-space problem by carpooling, then you may find that you are facing the problem of a work schedule that diverges from that of the person or people with whom you carpool. In other words, the solution to one problem gave rise to another problem, which then again needs to be solved through the problem-solving cycle.

CLASSES OF PROBLEMS

There are two classes of problems: those that are considered well defined and others that are considered ill defined. Well-defined problems are those problems whose goals, path to solution, and obstacles to solution are clear based on the information given. For example, the problem of how to calculate the price of a sale item is well defined. You see the original price on the tag, calculate the discount percentage, and subtract this amount from the original price. The solution is a straightforward calculation. In contrast, ill-defined problems are characterized by their lack of a clear path to solution. Such problems often lack a clear problem statement as well, making the task of problem definition and problem representation quite challenging. For example, the problem of how to find a life partner is an ill-defined problem. How do you define "life partner"? What traits should that individual have? Where do you look to find such a person? Only after considerable work has been done to formulate the problem can an ill-defined problem become tractable. Even at this stage, however, the path to solution may remain fuzzy. Multiple revisions of the problem representation may be necessary in order to find a path to a solution. In contrast to well-defined problems, ill-defined problems can lead to more than one "correct" solution.

The solution process for well-defined problems has been studied extensively, often using algorithms to describe how each step of a problem is solved (e.g., Newell & Simon, 1972). A well-defined problem can be broken down into a series of smaller problems. The problem may then be solved using a set of recursive operations or algorithms. In contrast, algorithms cannot be used to solve ill-defined problems precisely because the problem cannot be easily defined as a set of smaller components. Before a path to solution is found, ill-defined problems often require

a radical change in representation. For example, consider the following problem:

> You have a jug full of lemonade and a jug full of iced tea. You simultaneously empty both jugs into one large vat, yet the lemonade remains separate from the iced tea. How could this happen?

At first, this puzzle is difficult. You imagine two pitchers of refreshing drinks being poured into a common vessel and wonder how they could not mix. (It is safe to assume that the lemonade and iced tea have similar densities). However, if you change your mental representation of the lemonade and iced tea, you see that *frozen* drinks could be easily poured into the same vat without mixing. Though the problem itself does not specify the state of the drinks, most people assume that they are liquid, as is usually the case. But this constraint is simply an assumption. Of course, this puzzle is a fairly trivial one. But in life, we often make unwarranted assumptions in our everyday problem solving. Such assumptions can interfere with our ability to discover a novel solution to an ordinary problem.

PROBLEM RECOGNITION, DEFINITION, AND REPRESENTATION

Problem recognition, definition, and representation are metalevel executive processes, called metacomponents in Sternberg's (1985) triarchic theory of human intelligence. This theory proposes that metacomponents guide problem solving by planning, monitoring, and evaluating the problem-solving process. The metacomponents include such processes as (1) recognizing the existence of a problem, (2) defining the nature of the problem, (3) allocating mental and physical resources to solving the problem, (4) deciding how to represent information about the problem, (5) generating the set of steps needed to solve the problem, (6) combining these steps into a workable strategy for problem solution, (7) monitoring the problem-solving process while it is ongoing, and (8) evaluating the solution to the problem after problem solving is completed. In this theoretical context, the processes of problem recognition, definition, and representation correspond to the first, second, and fourth metacomponents, which are used in the planning phase of problem solving.

Problem recognition, also referred to as problem finding, is one of the earliest stages of problem solving. Getzels (1982) classified problems based on how they were "found." According to Getzels, there are three kinds of problems: those that are presented, those that are discovered, and those that are created. A presented problem is one that is given to the solver directly. In this case, there is no need to recognize or find the problem; it is stated clearly and awaits solution. A discovered problem, however, is one that must be recognized. Such a problem already exists, but it has not been clearly stated to the problem solver. In this case, the problem solver must put together the pieces of the puzzle that currently exist and seek out a gap in current understanding in order to "discover" what the problem is. In contrast to presented and discovered problems, the third class of problems comprises those that are created. Created problems are those in which the problem solver invents a problem that does not already exist in the field. For this reason, one can argue that a created problem will, in some sense, always produce a creative solution, simply because its problem statement deviated from the usual way of thinking about the problem. Getzels and Csikszentmihalyi (1976) found that artists who spent more time in the problem-finding stage while creating an artwork were judged to have more creative products than did artists who spent less time in problem finding. In fact, the artists who spent more time also remained highly creative seven years later. For the purposes of this chapter, problem recognition refers to both discovered and created problems.

Problem definition is the aspect of problem solving in which the scope and goals of the problem are clearly stated. For example, a presented problem may be easy to define if the problem statement has been prepared for the solver. However, some presented problems are not clearly stated, requiring the problem solver to clarify the precise definition of the problem. Discovered problems usually require definition because the problem solver has identified the problem in his or her field. Defining a created problem is likely to be a challenge, given that the problem solver has gone beyond the current field in inventing the need for a solution in the first place.

Problem representation refers to the manner in which the information known about a problem is mentally organized. Mental representations are composed of four parts: a description of the initial state of the problem, a description of the goal state, a set of allowable operators, and a set of constraints. By holding this information in memory in the form of a mental representation, the problem solver is able to remember more of the problem by chunking the information, in order to organize the conditions and rules of a problem to determine which strategies are useful, and to assess progress toward the goal state (Ellis & Siegler, 1994; Kotovsky, Hayes, & Simon, 1985; Newell & Simon, 1972). A problem may be represented in a variety of ways, for example, verbally or visually. Even a presented problem may require the generation of a new representation in order to be solved. For example, given the problem of finding your way to a new location, you may find it much easier to follow a map than to read a set of directions. If you have trouble following the map, then it may be worthwhile to write out a description of the route in words, re-representing the information in a way that makes it easier to get to your destination.

It is important to note that these three aspects of problem solving are not discrete, sequential stages in the solution process, but rather are interactive and often difficult to tease apart in a real problem-solving situation. When a problem is represented in a new way, the problem solver may decide to redefine the goal accordingly. Similarly, a redefinition may lead to a new representation.

It is useful to consider the roles of problem recognition, definition, and representation in the solution of well-defined versus ill-defined problems. Recall that a well-defined problem is one whose path to solution is straightforward, whereas an ill-defined problem is one that does not lend itself to a readily apparent solution strategy. Consider the following well-defined problem, referred to as the Tower of Hanoi problem:

> There are three discs of unequal sizes, positioned on the leftmost of three pegs, such that the largest disc is at the bottom, the middle-sized disc is in the middle, and the smallest disc is on the top. Your task is to transfer all three discs to the rightmost peg, using the middle peg as a stationing area, as needed. You may move only one disc at a time, and you may never move a larger disc on top of a smaller disc. (Sternberg, 1999)

The problem here is easy to recognize: One needs to move the discs onto the rightmost peg. The problem is also defined clearly; the relative sizes of the discs as well as their locations are easy to distinguish. Also, the solution path is straightforward based on this representation. Working backward, one realizes that the largest disc must be placed onto the rightmost peg, and in order to do so, the other two discs must be removed. So that the medium-sized disc does not end up on the rightmost peg, the smallest disc must first be moved to the far right. Then the medium disc is placed on the middle peg; the small disc is placed on top of the medium disc. The large disc is then free to be placed on the rightmost peg. Finally, the small disc is moved to the left so that the medium disc is free to move to the rightmost peg. The last step is then to move the small disc atop the other two and the problem is solved. Note that this well-defined problem can be expanded to include many pegs and many discs of varying sizes, but its solution will always proceed according to the algorithm described in this, the simplest case.

For the most part, well-defined problems are relatively easy to recognize, define, and represent. However, a well-defined problem may entail some degree of "problem finding," in the sense that a problem exists but must first be discovered. For example, a scientist may struggle to identify a gap in the existing literature on a problem, but the actual process of filling that gap may come easily once the problem itself has been identified. The solution to the discovered problem may follow a path similar to that of other problems in the field (e.g., experimental methods). For example, much early psychological research was conducted using male participants. When a researcher questioned the validity of the results for females, a new problem had been discovered. Given this new problem, the path to solution was well defined: Simply use the same experimental method but include female participants in the study. In this sense, this well-defined problem was somewhat difficult to recognize, yet once identified, it was easily defined and represented in familiar terms.

The representation of well-defined problems is not necessarily easy, however. Consider another problem:

> Three five-handed extraterrestrial monsters were holding three crystal globes. Because of the quantum-mechanical peculiarities of their neighborhood, both monsters and globes come in exactly three sizes, with no others permitted: small, medium, and large. The small monster was holding the large globe; the medium-sized monster was holding the small globe; and the large monster was holding the medium-sized globe. Since this situation offended their keenly developed sense of symmetry, they proceeded to transfer globes from one monster to another so that each monster would have a globe proportionate to its own size. Monster etiquette complicated the solution of the problem since it requires that: 1. only one globe may be transferred at a time; 2. if a monster is holding two globes, only the larger of the two may be transferred; and, 3. a globe may not be transferred to a monster who is holding a larger globe. By what sequence of transfers could the monsters have solved this problem? (See Kotovsky et al., 1985)

Most people find this problem to be more difficult than the Tower of Hanoi problem (Newell & Simon, 1972). However, it is actually directly isomorphic to (i.e., its structure is exactly the same as that of) the Tower of Hanoi problem. In this case, it is the difficulty of representing the problem correctly that increases the level of difficulty of the problem as a whole. After you are told of the isomorphism between the two problems, the solution is simply a matter of mapping relationships from one problem to the other. In summary, problem definition is usually easy for the class of well-defined problems; however, accurate problem recognition and representation are not necessarily straightforward, even when the scope and goals of the problem are clear.

In the case of ill-defined problems, however, it is often the case that all aspects of problem formulation are relatively challenging. Perhaps the easiest stage in attempting to solve an ill-defined problem is that of problem recognition. It is often relatively simple to identify a fuzzy problem. For example, it is easy to identify the problem of developing a test of creativity. It is hard, however, to define the exact contents of such a measure.

The real difficulty in solving an ill-defined problem is in clarifying the nature of the problem: how broad it is, what the goal is, and so on. Although well-defined problems have a clear path to solution, the solution strategy for an ill-defined problem must be determined by the problem solver. To develop a problem-solving strategy, it is first necessary to specify the goals of the task. For example, if we take on the task of designing a creativity test,

we must decide whether the goal is (a) to estimate the creativity of undergraduate psychology majors or (b) to measure creative potential among people of all ages and educational and cultural backgrounds. Before the path to solution can be constructed, the goal must be clear.

Representing information about the problem is also difficult in the formulation of an ill-defined problem. Consider again the problem of parking mentioned at the beginning of the chapter. The representation of the problem affects the solution. If we think of the parking problem in terms of parking spaces, we are likely to seek additional spaces when there are too many cars to park. However, if we think of parking in terms of too many idle vehicles, we are more likely to consider new ways of making use of the cars that have remained idle during the workday (e.g., driving other people who need transportation around the city). This latter perspective will guide us to seek solutions that maximize efficiency rather than maximizing the amount of concrete and asphalt in the downtown area. To solve a problem, it often is necessary or, at least, desirable to try out several representations of the problem in order to hit upon one that leads to an acceptable solution.

Problem-solving research has not revealed a great deal about the processes involved in problem recognition, problem definition, and problem representation. Indeed, the emphasis in research has been on the latter rather than the earlier phases of problem solving. Yet these earlier phases are critical to accurate and efficient problem solving, especially in the solution of ill-defined problems. The study of ill-defined problems generally has been less fruitful than the study of well-defined problems. Well-defined problems are well described by current theories of problem solving; however, ill-defined problems are ill understood by psychologists. Yet arguably most of the problems in the real world are not well defined. Most are fuzzy problems, often difficult to delineate and sometimes even harder to represent in a way that makes them solvable. Our current educational system better prepares children to answer questions that are well defined and presented to them in the classroom than it does to formulate the nature of problems in the first place. Often the skills involved in solving well-defined problems are not the same as those involved in recognizing a nonobvious problem or creating a problem. The skills needed clearly to state a problem and to represent information about it in a way that permits solution are also often not emphasized in current classrooms. In this chapter we consider what factors influence the metacognitive processes involved in recognizing, defining, and representing problems.

Research on problem solving has identified several variables that influence problem-solving performance. Among these are knowledge, cognitive processes and strategies, individual differences in ability and dispositions, as well as external factors such as social context. Those variables known to influence general problem solving will be examined with respect to the three particular aspects of problem solving that are the focus of this chapter: problem recognition, problem definition, and problem representation.

KNOWLEDGE

Everyone approaches a problem situation with a unique knowledge base. That knowledge base is essentially a set of expectations about the way the world works. As you began to read this chapter, your experience with reading chapters in similar books led you to expect a certain structure and content. Similarly, when you identify, define, and represent a problem, it is in terms of what you already know. For example, consider how the parking problem mentioned in the beginning of the chapter would be approached differently by individuals with different knowledge bases. An urban planner is more likely to identify or notice that problem as one of primary importance than is a person who does not live in an urban area. The urban planner is also more likely to consider different variables in defining the problem than someone from a small town. For example, the urban planner defines the problem in terms of how it may affect the city's income (e.g., parking meters or garages) and use the city's resources (e.g., administrative factors associated with employees and regulation of parking). In contrast, the small town resident may define the problem in terms of the esthetics of housing many vehicles (e.g., parking garages are often not welcome sights in small towns) because the solution of this problem is less likely to generate funds for the town than it would in an urban setting. According to the definition of the problem, the problem would be represented differently depending on the knowledge of the problem solver, be it an urban planner or small town parking supervisor. Problem-solving research has accumulated a tremendous amount of information regarding the relationship between knowledge and problem definition and representation and, to a lesser extent, regarding problem recognition.

It is important to keep in mind that knowledge may help or hinder problem solving. For example, knowledge plays an important role in the solution of analogies. In such problems, your task is to map the relationship between two items onto two other items. For example, *apple* is to *apple tree* as *pear* is to *pear tree*. The relationship here should be clear: You are pairing fruits with their respective trees of origin. Consider the following analogy problem.

Nefarious is to Dromedary as Eggs are to:
A: Chapel
B: Yellow
C: Bees
D: Friend (Concept Mastery Test; Terman, 1950)

The correct answer to this problem is bees. The mapping rule here is that the number of letters in each part of the analogy must match. The typical approach to analogy problems is to look for a semantic connection between the constituents rather than a surface similarity such as the number of letters. In this example, knowledge is actually an impediment to problem-solving success.

Everyday Knowledge and Problem Definition and Problem Representation

Research has demonstrated the effects of knowledge in general on problem solving, as well as its effect on domain-specific expertise. Most of this research has focused on problem representation and can also be applied to our understanding of problem definition. One source of evidence of the effect of knowledge on problem definition and representation stems from early research on the solution of well-defined problems.

Early problem-solving research sought to describe the problem-solving process as a set of steps in higher order, isomorphic problem spaces (e.g., Newell & Simon, 1972). Such research on problem solving and the concept of "problem space" grew from Newell and Simon's (1972) work on the General Problem Solver, or GPS, a model of human problem-solving processes. This model defined a problem as composed of a problem space, a starting state, a goal state, rules of transition, and heuristics. The problem space refers to all the possible states a problem could be in, such as during a bridge or checkers game. The starting state refers to the initial state of the problem. The goal state is the state to be reached by the system. Rules of transition refer to those functions that move the system from one state to another. Finally, heuristics are defined as rules that determine which moves are to be made in the problem space, as opposed to a random walk. Essentially, the GPS employs means-end analysis, a process that compares the starting state of a problem with the goal state and attempts to minimize the differences between the two. These components are well suited for solving well-defined problems where the space and transitions between states are unambiguous. However, the model offers no solution whatsoever for dealing with ill-defined problems. Nevertheless, the idea of a problem space has become a widely used and effective way of formalizing well-defined problems.

Recall the Tower of Hanoi and Monsters and Globes problems mentioned previously. According to the GPS, isomorphic problems should theoretically be solved similarly regardless of the way the information in the problem is represented. However, this model has been called into question by further studies of problem-solving performance on problems identified to be isomorphic to the Tower of Hanoi problem. Although these problems share with the Tower of Hanoi problem an identical problem space and solution structure, it is clear that the constituents chosen to represent the surface structure of each problem do have an effect (sometimes negative) on the mental representation of the problem space. One source of such evidence comes from a study that used isomorphs of the Tower of Hanoi problem involving acrobats of differing sizes (Kotovsky et al., 1985). Consider one such isomorph:

> Three circus acrobats developed an amazing routine in which they jumped to and from each other's shoulders to form human towers. The routine was quite spectacular because it was performed atop three very tall flagpoles. It was made even more impressive because the acrobats were very different in size: The large acrobat weighed 700 pounds; the medium acrobat 200 pounds; and the small acrobat, a mere 40 pounds. These differences forced them to follow these safety rules.
>
> 1. Only one acrobat may jump at a time.
> 2. Whenever two acrobats are standing on the same flagpole one must be standing on the shoulders of the other.
> 3. An acrobat may not jump if someone is standing on his shoulders.
> 4. A bigger acrobat may not stand on the shoulders of a smaller acrobat.*
>
> At the beginning of their act, the medium acrobat was on the left, the large acrobat in the middle, and the small acrobat was on the right. At the end of the act they were arranged small, medium, and large from left to right. How did they manage to do this while obeying the safety rules?
>
> *For the Reverse Acrobat problem this rule was reversed so that the smaller acrobat could not stand on the larger one; thus, the large ones had freedom of movement in that version. (Kotovsky et al., 1985, p. 262)

In the reversal of the situation where the large acrobats were standing on the smaller acrobats, participants took significantly more time to solve the problems. When an individual's expectations about a problem are violated (i.e., smaller acrobats should stand on top of larger acrobats), it requires more time successfully to build and navigate a solution to the problem. Alternatively, performance was facilitated when the information presented was in synchrony with the individual's knowledge, or in a form that did not lead to inadequate representations. Clement and Richard (1997) again used the Tower of Hanoi framework to examine problem solving, coming to the conclusion that the most difficult versions of the problem were those that required an individual to abandon their initial point of view in favor of a new, more appropriate one.

These findings pose a challenge to the idea that an individual's representation of a problem is based solely on structure, as implied by the GPS model. Even when the structure of two problem spaces is identical, the solution of those problems will depend on dissimilarities in surface elements and modalities of thought (Kotovsky et al., 1985; Simon & Newell, 1971). Simply put, these results show that one does not enter a problem as a blank slate. Prior knowledge provides a tool to structure the information in the problem, allowing the individual to apply a familiar scaffold to the information, regardless of how helpful or harmful it might be. Prior knowledge mediates an individual's ability to represent the problem in the most efficient fashion.

There is also evidence to suggest a developmental trend in the ability to use knowledge, a skill that affects problem definition. Siegler (1978) found that older children outperform younger children on a balance-scale task because of their attention to all the relevant information about the problem. Older children realize that it is necessary to encode information about multiple dimensions of the task, but younger children do not without prompts to do so. Thus, to the extent that problem definition relies on the knowledge that multiple sources of information need to be attended to and encoded, the skill of defining problems will also increase with age.

Expert Knowledge and Problem Definition and Problem Representation

Prior knowledge has been discussed in terms of everyday knowledge about the world; however, research in cognitive psychology has found a qualitative distinction between the knowledge of individuals who have more or less experience with a particular domain. Specifically, studies show that individuals who have accumulated considerable knowledge in a domain represent information about problems differently from the ways these problems are represented by individuals without extensive knowledge bases (see Chi, Glaser, & Farr, 1988). Often experts have more efficient representations of their domain than do novices. These representations have stripped away irrelevant details and get at the deeper structure of the problem, in part by chunking information. These differences in knowledge structure affect the way an expert identifies, defines, and represents problems. For example, experts and novices typically differ in how they define problems, as illustrated in the following example.

Two groups of students were given physics problems and asked to sort them into several groups, based on their similarity (Chi, Feltovich, & Glaser, 1981). The students were either graduate students in physics (experts) or undergraduates with some physics knowledge (novices). Level of expertise determined how the students defined the problems. The novice students organized their problems based on the surface features of the problem, such as whether the problem contained a spinning object, a falling object, or some other similar surface feature. The graduate students, in contrast, organized problems based on deeper, structural similarities, such as what principles of physics were required to solve the problems. This sort of deep-level process is exactly what is needed to sift through most of the unimportant information contained in the texts of many well-defined problems. It also is most likely what impairs people when they are confronted with problems that present the information in a fashion that causes them to frame the problems in an inappropriate manner.

The expert-novice differences in problem representation are well illustrated by the famous studies of chess expertise. Chase and Simon (1973) studied the reconstructive memory of individuals for arrangements of chess pieces on boards. The chess experts performed better than the novices in reconstructing the board when the pieces were placed as they would be in the middle of a chess game. However, when the pieces were arranged randomly, the experts performed no better than the novices, suggesting that the violation of these deep-level rules about the structures of chess lessened the usefulness of the expert knowledge. Experts' mental representations of chess pieces on a chessboard are more sophisticated than those of novices in that they contain more chunked information. When chess pieces are arranged on the board randomly, expert mental representations based on familiar board configurations are of no help. Randomly placed pieces cannot be chunked together according to patterns that naturally occur in chess play, rendering expert players as naive as novices when it comes to remembering random arrangements of pieces.

Empirical studies of problem solving have demonstrated a distinction between expert and novice problem representation in terms of the time spent on various stages of the problem-solving process (Lesgold, 1988). Specifically, Lesgold found that experts spent more time determining an appropriate representation of the problem than did novices. Novices were found to represent the problem relatively quickly and spend their time working on a solution. In contrast, experts spent more time comparing their current knowledge to the information they needed to discover in order to best represent the problem. After the problem was set up in the expert problem solver's mind, the process of solving it proceeded quickly relative to the novices. Thus, the effect of expertise provides the problem solver with skills that aid problem solving from the very early stages. Because novices may not notice the flaws in their representations of the problem, they will often be forced to start over, forfeiting a lot of hard work on a poorly represented problem. An expert's well-organized knowledge base is better equipped to assess the appropriateness of a problem representation even before further work is done on the problem.

While expertise is often hailed as a key to problem-solving success, it seems that the development of a highly specialized body of knowledge can lead to an impairment in the ability of experts to incorporate new rules into their thinking or to modify older ones. For example, Frensch and Sternberg (1989) have studied expert and novice bridge players. In games of bridge, the expert players performed much better than the novice players when a surface rule was changed. However, when a deeper rule was changed (for example, the rules that specified who played the lead card on the next trick), the experts' performance deteriorated more, in the short run, than did that of the novices. Frensch and Sternberg concluded that experts' entrenched strategies interfered with, rather than facilitated, their performance. The preceding examples highlight the fact that even though experts often both define and represent problems differently than do novices, the experts can suffer when the fundamentals of their representations are altered, resulting in significantly different performance profiles.

Problem Recognition

Problem recognition occurs with respect to the knowledge a person has about a domain. The fact that an expert's knowledge about a domain is organized differently from that of a novice will affect the nature of the problems that are recognized in a domain. Studies of creativity have found that it requires a considerable amount of expertise in a domain before an individual begins to recognize and create valuable new problems (Csikszentmihalyi, 1996; Simonton, 1999). Only after a person knows a field well can that person recognize gaps in the field's body of knowledge; novices are more susceptible to recognizing problems that have already been addressed by the field in the past. Not only do experts need to be thoroughly familiar with their domain; Csikszentmihalyi and Sawyer (1995) found that problem recognition often also involves the synthesis of knowledge from more than one domain. It is unfortunate that so few researchers have directly examined the effect of knowledge on problem recognition.

Both everyday knowledge and expert knowledge of a particular domain play an important role in the recognition of a problem, as well as the nature of a problem's definition and representation. However, more research has focused on the latter than the former aspects of problem solving. The next section considers the *process* of using knowledge in the course of problem solving.

COGNITIVE PROCESSES AND STRATEGIES

How do cognitive processes and strategies play a role in problem recognition, definition, and representation? Mumford, Reiter-Palmon, and

Redmond (1994) have developed one of the few models that attempts to describe the cognitive processes involved in the early stages of problem solving. Their model of problem construction proposes a set of processes that are implemented in finding, defining, and representing problems. First, problem solvers must be aware of cues, patterns, and anomalies in the environment (attention and perception). Second, analogous problem representations must be accessed from memory (activation of representations). Third, these representations must be evaluated (screening strategy selection). Fourth, the goals and constraints of the problem must be defined (element selection strategy). Fifth, these elements of the problem must be represented mentally (element reorganization).

Consider again the example of finding a life partner in the context of this model. First, the problem is recognized through attention to cues in the environment, such as noting who you are, what your needs are, and what type of person might possess the qualities you are seeking. Second, as you think of where to find such an individual, you consider analogous problems, such as how you went about selecting a suitable career or how you found friends when you moved to a new area. Third, you screen these possible analogous representations for importance. Whereas the strategy of choosing friends may have been governed by proximity and common interests, you may find that the strategy of choosing a career is more appropriate to finding a life partner if your career is one that you are passionate about, that takes into account your values and interests, and that is something that you are committed to for the long term (as opposed to a superficial friendship, which may last only as long as you remain in the same city or neighborhood). Fourth, you examine the goals and constraints of the problems. For example, it may be more important to consider the compatibility of lifestyles (e.g., career, values) with a life partner than it is with a friend. That is, you may maintain friendships with individuals whose political or religious ideals are very different from your own, but you would be less likely to choose to initiate a romantic relationship with someone with incompatible values. Fifth and finally, all of the considerations you have identified as relevant to finding a life partner are represented in a way that makes it possible to conceptualize who that person might be.

Processes in Problem Recognition

Another model of problem solving has focused more specifically on problem recognition. Brophy (1998) described a series of processes that artists and scientists report engaging in prior to defining a problem. These presymbolic processes set out the goals and obstacles in a problem situation. Brophy described these processes as "unconscious, intuitive thought that combines perceptual pattern recognition, abstract analogy creation, and search for useful ways to organize experience in problem domains" (p. 126). This idea is echoed more explicitly by Goldstone and Barsalou (1998), who suggested that while the early phases of our concepts may be couched in perceptual imagery, later abstractions arise as a function of the transformation of these nascent perceptual objects. While it is not clear just how reliable introspective self-reports are (Nisbett & Wilson, 1977), the support for these perceptually based concepts (Barsalou, 1999; Goldstone & Barsalou, 1998) lends credence to the idea that early stages of problem formation employ these presymbolic processes.

Although there is not a large body of research on these presymbolic processes or the process of problem recognition, we suggest one possible hypothesis in regard to the phenomenon of problem finding. This hypothesis is that problem recognition in a given domain depends on a sensitivity to gaps in domain knowledge that cannot be filled in by interpolating information from the existing knowledge space. Put more simply, when a person knows a certain amount of information about a domain, there will be holes in his or her knowledge, and if the person is unable satisfactorily to fill these gaps, the person will seek to fill these gaps. This hypothesis complements the Mumford et al. (1994) model in that it requires the problem solver to have a reasonable internal representation of the knowledge space and to be attentive to gaps in that knowledge.

Problem recognition as sensitivity to gaps is also consonant with Boden's (1999) model, which describes creative problem solving as the exploration and possible transformation of a psychological (or computational) knowledge space. Boden proposes that creativity is embodied in an agent exploring its knowledge space in a domain, and that creative products are created by tweaking and transforming these spaces in accordance with computational approaches to information processing. As an individual explores his or her knowledge, he or she is likely to recognize gaps or see patterns in the knowledge base, leading to the recognition of new problems. This research supports the hypothesis that problem recognition is heavily reliant on the type of information encountered and explored by the individual.

Processes in Problem Definition and Representation

Research on specific processes involved in problem solving has described problem solving in terms of algorithms, analogical transfer, convergent and divergent thinking, as well as incubation and insight. Before examining each in relation to the early stages of problem solving, let us define the constructs. As mentioned previously, algorithms are sets of operations often applied recursively to solve a problem. Analogical transfer is a process by which a problem is solved by mapping its components onto a similar problem whose solution path is already known. Convergent thinking refers to the process of narrowing down a set of ideas in order to converge on the most appropriate one. Divergent thinking is the process of generating multiple ideas in order to create a set of possibilities from which to choose. Incubation is a stage of problem solving in which the problem is set aside and not worked on consciously, but which may lead to a solution, often manifested in a sudden moment of insight. Though these processes have been studied with regard to the whole problem-solving process, we are interested in the operation of these processes in problem definition and representation.

After the problem has been recognized, the process of defining and representing the problem may proceed with processes such as analogical thinking. To form an appropriate representation, a problem solver must often try out several different perspectives on a problem before finding one that gives insight to a solution path. One way in which a variety of representations can be found is through analogical thinking. When an analogous problem can be identified, then the solution of the present problem is partly a matter of mapping one element onto another (Reed, 1987). For example, mapping involves comparing the problems for similarity in structure and identifying their parallel elements. The solution of one problem then can guide the process of solving a novel one through this analogical mapping process.

When an appropriate analogy is found, the problem solver may experience a leap in understanding – an insight. Some researchers consider insight to reflect a sudden restructuring process that yields an immediate understanding of the path to solution (Metcalfe & Wiebe, 1987). Other researchers disagree with this view, claiming that insight is incremental and does not reflect any sudden changes in representation (Weisberg & Alba, 1981). However, the current point is that re-representation of a problem can lead to a new and different solution path. Consider this example of a problem, which often yields an insight upon solution:

> A man who lived in a small town in the U.S. married 20 different women of the same town. All are still living and he has never divorced one of them. Yet he has broken no law. Can you explain?

You may find this problem difficult to solve until you remember that the verb "to marry" can also mean "to perform a marriage." Until an appropriate representation of the problem is found, the solution to the problem remains elusive.

Many psychologists have attempted to explain the processes underlying insight. Gestalt psychologists (Wertheimer, 1945) as well as contemporary psychologists (Metcalfe & Wiebe, 1987) have described insight as a sudden understanding that results when the problem solver realizes how all parts of the problem fit together to form a coherent whole, or *Gestalt*.

Other psychologists have criticized this view, claiming that the processes involved in having an insight are nothing special, and are in fact no different from the processes implicated in solving a problem that does not involve insight (Weisberg & Alba, 1981).

Still other psychologists (Davidson, 1995; Sternberg, 1985) have proposed a three-process theory, according to which insights arise out of processes called selective encoding, selective combination, and selective comparison. Selective encoding refers to the process of attending to and encoding information that is relevant for the solution of a particular problem. Selective combination is the process of recombining elements of the problem in a way that changes the representation of the problem. Selective comparison is the processing in which elements of the current problem are recognized as related to problems that have been encountered in the past. Any one of these three processes can lead to a change in problem definition or representation, possibly resulting in an insight.

What leads to an insightful moment of re-representation? Some researchers have claimed that a period of time spent away from the problem may help in the incubation of ideas and thus lead to an insight. Wallas's (1926) model suggests that after the period of (1) preparation, in which relevant information is gathered about the problem, a period of (2) incubation follows, and after this, time is spent away from the problem, and then a moment of (3) illumination occurs. The solution is then subject to (4) verification. Various researchers have tried to test this model. Two tests are described below.

Smith's (1995; Smith & Blankenship, 1989) research on incubation suggests that a period of time spent away from the problem can allow the problem solver to let go of unfruitful approaches and to allow an appropriate representation to come to mind, thus culminating in a moment of insight. Smith explains that initial, failed attempts to solve a problem interfere with the solver's ability to access the correct solution. Only after the solver takes a break from the problem can the initial misleading solution paths be forgotten so that new, accurate solution paths may be found. Other theories of incubation propose that the incubation period allows for the assimilation of new information, which then is incorporated into the solution of the problem (Seifert, Meyer, Davidson, Patalano, & Yaniv, 1995). According to this theory, incubation not only allows the problem solver to let go of misleading information, but also provides an opportunity to notice new information that helps form a viable mental representation of the problem. Neither of these theories requires special cognitive processes in order to explain the evolution of an insight.

The metacognitive task of how to represent information given in a problem is subject to the effects of fixation and negative transfer (Gick & Holyoak, 1980, 1983). Fixation occurs when an individual gets stuck in a particular way of looking at a problem. When a person is attempting to solve the problem mentioned above about a man with multiple marriages, that person may become fixated on the fact that one person cannot marry several times without being married to more than one person. Only when a person lets go of the misleading (though more common) definition of the word "marry" can the person break this fixation.

Fixation is a common result of the ordinary processes of problem solving. When faced with any type of problem, an individual brings to the task his or her experience with similar problems, such as the knowledge about the domain and the individual's expectations or intuitions about how to approach the problem. Often schemas provide useful short-cuts in the solution of well-defined problems. For example, most people have schemas for solving word problems in math, based on their previous experience with such problems (Newell & Simon, 1972). Usually, we examine the question and use the given numeric values to set up a familiar formula for solution. However, when a problem's definition and its goals are ill structured, our expectations about how the problem should be approached may be more detrimental than helpful. In fact, the key difficulty in many insight problems is that they are based on the premise that the problem solver will build on an incorrect or misleading expectation that must be overcome in order to solve the problem.

For example, consider the following problem:

> If you have black socks and brown socks in your drawer, mixed in a ratio of 4 to 5, how many socks will you have to take out to make sure that you have a pair of the same color?

When people see a problem involving numbers, they usually assume, correctly, that there are some calculations to be done. Therefore, they concentrate on the numerical information, in this case the ratio information, in pursuing a solution (Davidson, 1995). However, this assumption is an example of negative transfer, a misleading expectation. If the problem is represented without this numerical information, we notice that it can be solved in a straightforward manner without considering the ratio information at all: Pull out two socks and they may match. If not, the third sock will definitely match one of the other two, given that there are only two colors of socks in the drawer.

Based on the limited amount of research that has been done on the information-processing components of problem recognition, definition, and representation, it appears that these aspects of problem solving may not require special kinds of thinking. However, attention and openness are likely to be crucial to the discovery and creation of problems and to the selection of a problem representation. The metacognitive processes involved in these early stages of problem formulation are both divergent and convergent and appear to rely on analogical thinking as well as incubation and insight.

INDIVIDUAL DIFFERENCES: ABILITIES AND DISPOSITIONS

Traditionally, problem solving research has not focused on the role of individual differences beyond a consideration of general cognitive ability. However, psychologists who have examined the early stages of problem solving have found that there are important sources of individual variation that affect the processes of problem recognition, definition, and representation.

Individual differences have been found to play a role in the early stages of well-defined problem solving (MacLeod, Hunt, & Mathews, 1978; Sternberg & Weil, 1980). For example, MacLeod et al. (1978) found that individual differences in ability influence problem representation. In their study, participants were presented with simple declarative sentences such as "Plus is above star." Their results showed that most participants represented the sentence linguistically. In contrast, participants who had high spatial abilities were more likely to represent the content of the sentence pictorially. The authors concluded that the processes in sentence comprehension are not universally generalizable, but rather depend on the abilities of the individual. Similarly, mental representations of problems are also affected by individual differences in ability.

Getzels and Csikszentmihalyi (1976) found that individuals who were successfully creative exhibited a concern for problem finding throughout the creative process. This "concern" can be characterized as a disposition or a mental set that attends to the nature of the problem definition and representation throughout the process of solving the problem at hand. Their study found that the most products were produced by individuals who reevaluated the way they had initially defined and represented the problem during all stages of the problem-solving process.

One source of information about the abilities and dispositions that may be influential factors in the processes of problem recognition, definition, and representation in ill-defined problem solving is the literature on creativity. As discussed earlier, the processes of recognizing a problem, redefining problems, and representing them in various ways are essentially creative processes. The creativity literature has identified several individual-difference variables that appear to influence creative problem solving, including divergent thinking, openness, tolerance of ambiguity, and intrinsic motivation.

Do some people have the ability to think more divergently or flexibly than others? Individual differences in intelligence and personality have been linked to differences in creative performance in various studies (see Sternberg & Lubart, 1995). Psychologists have often pointed out the importance of divergent-thinking abilities in creative problem solving. One way divergent thinking has been measured is using the Torrance Tests of Creative Thinking (Torrance & Ball, 1984), which include several measures of an individual's ability to think divergently and flexibly. For example, the Alternate Uses Task asks participants to name as many uses as they can for an everyday object, such as a paper clip or an eraser. Responses of great diversity and number allegedly indicate greater divergent thinking ability and cognitive flexibility. Scores on the Torrance Tests have been associated with greater creative performance. This association between divergent thinking and creativity may be due to the ability to think of many and diverse ways of defining and representing a problem. Thinking divergently and flexibly may not help in the latter stages of problem solving, when a solution must be evaluated for accuracy; evaluation relies on analytical and convergent thinking abilities. However, divergent thinking ability is more likely to be critical in the early stages of solving, when the problem remains open-ended and various definitions and representations of the problem must be considered.

As mentioned earlier, one of the critical processes associated with problem finding is attention to and perception of the environment in which a problem is discovered (Mumford et al., 1994). Research on creativity has demonstrated that highly creative individuals are those who have a broad range of attention relative to less creative people. When experiencing the world, creative people tend to filter out fewer distracters in the environment (Eysenck, 1997). Because creative individuals take in information that other people would consider irrelevant, a highly creative person's chances of detecting subtle patterns and hidden anomalies are greater than the chances of a less creative person doing so.

Besides abilities, are there dispositional traits, such as personality attributes or cognitive style, that predispose people to being able to identify problems and realize creative ways to define and represent them? Many psychologists have argued that dispositions are a key factor in problem finding (e.g., Ennis, 1987; Jay & Perkins, 1997). Jay and Perkins (1997) have claimed: "Abilities, knowledge, and strategies enable a person to problem find, and contexts provide the stimulus, but it is dispositions that actually promote the initiation of problem finding" (p. 286). Jay (1996) found that problem-finding behavior was enhanced when it was encouraged and guided. Given the fact that real-world problem-solving situations often do not include such guidance and prompts, it appears that the disposition *spontaneously* to engage in problem-finding behavior is very important. Perhaps individuals who are prompted to take a lot of time during the identification, definition, and representation phases of problem solving will eventually internalize these strategies and spontaneously engage in problem-finding behavior, even in the absence of prompts and encouragement to do so.

Are there personality traits associated with creative problem solving? Quite a bit of research has sought to find a link between personality and creativity. In a meta-analysis of the relationship between personality traits and creativity, Feist (1998) found that creative individuals tended to be

"autonomous, introverted, open to new experiences, norm-doubting, self-confident, self-accepting, driven, ambitious, dominant, hostile, and impulsive" (p. 299). Other traits associated with creativity include tolerance of ambiguity (MacKinnon, 1978; Sternberg & Lubart, 1995) and intuitiveness (Bastick, 1982).

Eysenck (1997) has discussed the creative individual in terms of ego strength and psychopathology. Ego strength is a term used by Barron (1969) and others to refer to a strong, self-determined, dominant, self-reliant, and independent person. Eysenck has found a link between creativity and subclinical levels of psychoticism as measured by the Eysenck Personality Questionnaire (Eysenck & Eysenck, 1975). Eysenck conceived of psychoticism as a continuum ranging from conventional, socialized, and altruistic traits to aggressive, impulsive, and psychotic traits. Creative individuals were found to be slightly more psychotic than average with respect to this continuum. This observation has been supported by various reports of heightened levels of actual psychopathology among creative populations (e.g., Kaufman, 2001).

Most research that has attempted to identify the personality characteristics associated with creativity has found a great deal of variability among creative individuals, suggesting that the ability to create problems and solve them in a way that is considered useful and original may vary greatly from domain to domain. For example, the traits that are associated with being a creative visual artist may be very dissimilar from the traits associated with being a creative business manager. For a creative visual artist to transform his or her creative idea into a reality, he or she often must spend long hours in the studio. But a creative business manager will probably need to interact intensely with many different types of people in order to carry out her creative vision for her organization.

Another important factor that has been identified as critical to the creative process (e.g., Amabile, 1996), as well as to the early stages of problem solving, is motivation. It is logical that you will not recognize problems that you are not motivated to find. For example, recall the problem of lack of parking mentioned at the beginning of this chapter. If you walk or take public transportation to work every day, you may not even notice, let alone be concerned with, the problems facing automobile commuters. If you lack intrinsic motivation, you are less likely to pursue a difficult problem such as this one. Extrinsic motivation can also encourage creative problem solving if it provides more information or somehow makes it easier to solve the problem; however, extrinsic motivation that simply offers a reward but does not aid the problem-solving process (such as being paid to work on the downtown parking problem despite your lack of interest in the issue) will not lead to more creative solutions (Collins & Amabile, 1999). Amabile (1996) has also noted the importance of curiosity and a playful attitude in the facilitation of creative problem solving. People who enjoy experimenting with unusual ideas are more likely to recognize novel ways of defining and representing problems, in the same way that curious people are more likely to discover or create problems that escape the awareness of others.

These abilities and dispositions have been associated with creativity. However, the relationship of these with problem recognition, definition, and representation remains to be investigated carefully. Individual difference variables that are associated with creativity may prove to be a fruitful starting point for further research on the factors that influence the early stages of problem solving.

SOCIAL CONTEXT

Any discussion of problem-solving abilities must survey the environment in which an individual encounters a problem. Peers, culture, and even language structure play a role in the recognition, definition, and representation of a problem.

Social forces can influence substantially an individual's efforts in creatively defining, recognizing, or representing a problem (e.g., Sternberg, Kaufman, & Pretz, 2001; Sternberg, Kaufman, & Pretz, 2002). When an individual recognizes a problem in his or her field, this recognition may be viewed as "rocking the boat." The existence of a new problem may suggest an overlooked or ignored shortcoming in a field or situation. The social context affects problem recognition and definition through the field's adherence to current paradigms. For example, problems studied in the field of social cognition previously employed social-psychological methodology to examine the effect of beliefs about social groups on behavior. However, recent attraction to the use of functional magnetic resonance imaging techniques in research by neuroscientists and cognitive psychologists has become a tool of interest to some social psychologists who are interested in social cognition (e.g., Cunningham, Johnson, Gatenby, Gore, & Banaji, 2001). The availability of such resources, the field's acceptance of the validity of the methodology, as well as the neuroscience community's acceptance of social psychologists will affect the way that social psychologists discover and define problems in their field, especially among researchers interested in embarking on the new subdomain of "social cognitive neuroscience" (Ochsner & Lieberman, 2001).

Problem definition is affected by social context in any domain. Individuals can become unable to redefine problems or evaluate progress on current problems due to the attitudes of the group. For example, in an office environment, individuals may be familiar with a particular computer application for word processing. However, the program eventually may become outdated or unsupported. Initially, the group may simply go through the process of converting files or rewriting documents, rather than abandoning the program for one that is more appropriate. Here the problem has become not word processing, but rather the word processing program itself. The problem is not particularly difficult to spot, but the ways of the group may be so entrenched that changing programs becomes an unacceptable option. In other words, the attitudes of a group can be pervasive in the decision process of the individual.

The influence of the social context on problem recognition can be illustrated by an example from the field of psychology. In the late 1950s, Rosenblatt (1958) developed neural networks using elements that were designed to model human cognition, which he called perceptrons. Following this early work, other researchers in the field pointed out limitations of Rosenblatt's networks (Minsky & Papert, 1969). Minsky and Papert claimed that these early networks were unable to solve classification problems whose solutions were nonlinear (Beale & Jackson, 1990). Based on the argument that most interesting problems attempted by humans often require a nonlinear solution, this weakness was regarded as a fatal flaw in Rosenblatt's network design. As a result of the field's influence, there was little research in the field of neural networks for almost three decades; networks had been deemed inappropriate for modeling cognition. It was not until much later that the field gave neural networks another chance (Rumelhart, McClelland, & University of California San Diego, 1986). Rumelhart and McClelland's new vision of neural networks illustrated that such models did have the power to model more complex human cognition, and resulted in a rush of research interest in this area. Despite the fact that there was not a tremendous amount of evidence against the viability of neural networks at the time of Minsky and Papert's critique, the social context of the field hindered the progress of research in this vein for quite some time.

The social context has a strong, sometimes unnoticed, effect on problem solving, beginning with the very early stages. Immediate clues from the environment can affect the type of definition or representation used to solve a problem (Gick & Holyoak, 1980, 1983). Even the traditions and attitudes of a group will affect the types of problems recognized by its members, the terms in which they define those problems, and the ways they represent the problems as they prepare to solve them. Often, the most difficult part of problem formulation requires an individual to call into question these norms and expectations in order to most appropriately examine the phenomenon of interest.

SUMMARY AND CONCLUSIONS

What We Know

The earliest stages of problem solving involve recognizing that a problem exists, defining the scope and goals of the problem, and representing information about that problem in a way that helps establish a viable path to solution. For the most part, research on problem solving has focused on explaining the solution of well-defined problems that are already recognized and presented directly to the problem solver.

When we approach a new situation, our knowledge based on prior experiences will influence our ability to define and represent a problem correctly. In fact, we may fail to notice the existence of a problem if it runs counter to our strongly held expectations. To the extent that an individual has misleading expectations or schemas about a problem, due either to crystallized expertise or to the effects of misleading context, that person may have difficulty thinking flexibly about how to approach the dilemma. Recall the lemonade and iced tea example. Our assumption that lemonade and iced tea are beverages in liquid form impedes our ability to think of them in any other form.

The processes involved in problem recognition, definition, and representation are quite varied. To notice a problem, a person must attend broadly to all pieces of relevant information in a situation. Additional knowledge from past experience with similar problems must also be accessed. However, the likelihood that an individual will spontaneously notice analogies between problems in disparate domains is rather small (Gick & Holyoak, 1980). Individual differences in cognitive abilities and personality may explain why some people are better at solving ill-defined problems than are others.

The ability to think divergently and flexibly is valuable in the process of problem formulation, as is an open and intrinsically motivated disposition. Perhaps the most critical variable in determining whether a person discovers or creates a novel problem is that individual's motivation to find it and work on developing an appropriate definition and representation of the issue. This disposition characterized by openness and curiosity may be regarded as a trait version of a mental set, a constant metacognitive attentiveness to the environment and the process of problem solving. Individuals with this disposition are always thinking of different ways to regard the information in their environment and the information they possess in long-term memory. When they are working on a problem, they naturally attempt to redefine and re-represent the problem, thus increasing their chances of finding a definition and representation that will yield a creative solution.

Finally, the social context may also facilitate the likelihood of noticing problems and thinking divergently about their solutions. If an environment does not encourage potentially creative individuals to seek and explore, they will not discover gaps in their understanding, and they will not learn to play with ideas nor practice taking different perspectives on problems with which they are confronted.

What We Need to Know

In contrast to the later stages of problem solving, the stage of problem formulation appears to rely more heavily on disposition and social context. Unfortunately, relatively little empirical research has addressed these topics. We need to understand what makes a person more likely to engage him- or herself in seeking out ill-defined problems and experimenting with various ways to represent them. We need to know how people who are constrained by misleading expectations and schemas break out of their mental sets in order to gain new perspectives on problems. Can we teach children to think with this kind of mindful curiosity? We hope that teachers will allow children to practice suspending their judgment when necessary, to be playful in their search for a variety of solutions to problems.

If our ultimate goal is to help people become better able to solve problems that confront them in their personal and professional lives and in the concerns of the world, we must be prepared to examine the fuzzy issues surrounding problem recognition, definition, and representation. Because most of life's problems are not cleanly packaged with one correct path to solution, it is important that we take on the ill-defined challenge of studying these early phases of problem solving in an effort to understand how problem solving can be enhanced in these initial stages. Rather than educate others to become followers, it is in our best interest to encourage problem solvers to become active problem finders, to stay curious so that they discover and create novel problems, and to think flexibly in the process of solving those problems.

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2

The Acquisition of Expert Performance as Problem Solving

Construction and Modification of Mediating Mechanisms Through Deliberate Practice

K. Anders Ericsson

How do experts reach their high level of performance? Recent reviews (Ericsson, 1996, 1998b, 2001; Ericsson & Lehmann, 1996) dispel the common belief that "talented" expert performers attain very high levels of performance virtually automatically through cumulative domain-related experience. Instead, empirical evidence strongly implies that even the most "talented" individuals in a domain must spend over ten years actively engaging in particular practice activities (deliberate practice) that lead to gradual improvements in skill and adaptations that increase performance.

In this chapter I argue that the acquisition of expert performance can be described as a sequence of mastered challenges with increasing levels of difficulty, such as playing pieces of music, performing challenging gymnastic routines, and solving complex mathematical problems. Different levels of mastery present the learner with different kinds of problems that must be solved for the skill to develop further. And each individual's path toward skilled performance is distinct; it depends on when technical challenges were encountered and the specific methods used to help the individuals continue their development.

When beginners are first introduced to a domain of expertise they can successfully perform only the most simple tasks and activities. With the aid of instruction and training many individuals are able to master increasingly difficult tasks, thus gradually improving and slowly approaching the level of expert performers. The incremental nature of gaining mastery means that tasks that were initially impossible to perform can be executed effortlessly as increased skill is attained.

When an individual attempts to perform a task that is too difficult, his or her available repertoire of methods and skills is insufficient to perform the task successfully. In this chapter I argue that when motivated individuals strive to overcome obstacles and master prerequisite aspects of a given task, they must engage in problem solving. Studies of how individuals eventually master various types of problems should provide unique insights into