REINVENTING PSYCHOLOGY

by Robert J. Sternberg

Most of us spend much of each day thinking—about our work, the world we live in, and whatever comes to our attention. Cognitive psychologists are scientists who think about thinking itself. Can we identify the mental processes involved? If so, how do we use them? How might we improve them?

Serious people have been pondering the nature of thought for centuries. As a scientific pursuit, however, the study of thinking—cognition—is relatively new.

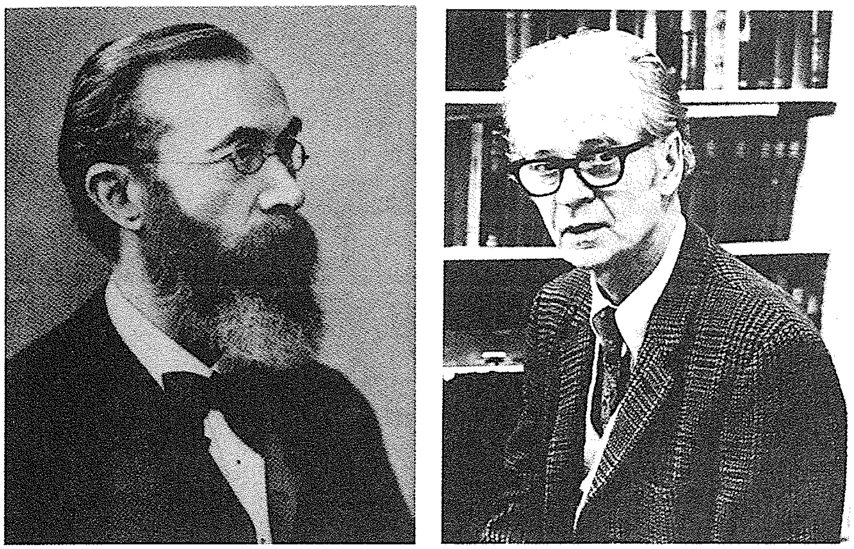
When Wilhelm Wundt, the German experimental psychologist, launched what he called the science of immediate experience during the late 19th century, scientific study of all kinds was flourishing. Physics, the most "objective" of all the disciplines, was probing the mysteries of matter and energy. But man, too, was a subject of wide interest, spurred in part by Charles Darwin's theory of evolution through natural selection. Physiologists approached the human body as an apparatus ruled by the laws of physics and chemistry. The psychologists, aiming to be as methodical as anyone else, also dealt with man as mechanism—*l'homme machine* as 18th-century philosopher Julien de La Mettrie put it. They focused on the observable and measurable. A distance was to be kept from what the founder of psychoanalysis, Sigmund Freud, would call "psychic reality."

But how to explore the mind's workings? In 1868, the Dutchman Frans Donders suggested that a start be made with a "subtraction method." For instance, he said, the time required to add two one-digit numbers could be found by subtracting the time it took to add four such numbers from the time needed to add five. Donders studied many mental operations in this way.

Modern cognitive psychology might have developed from that simple beginning, but it did not. Donders's work was attacked.

Critics argued that his method was scientifically invalid; there was a chance that subtraction itself altered the mental operation being studied. Enough psychologists shared this and other worries to abandon Donders's approach.

Psychology then took divergent paths. One was the stimulus-response approach championed by John B. Watson, in *Behaviorism* (1925), and further developed by Harvard's B. F. Skinner and others. To the behaviorists, mental processes were



The 19th-century German Wilhelm Wundt launched psychology as the study of mental processes; Harvard's B. F. Skinner and others shifted the focus to behavior, but now the science is again dealing with processes.

largely irrelevant. They aimed to explain behavior wholly in terms of punishment and reward, carrot and stick. This idea seemed to promise "results," and came to dominate psychology, especially in the United States and the Soviet Union.

The other path was the Gestalt, or "holistic," approach of the Germans Wolfgang Kohler and Max Wertheimer. They thought mental processes critical to organizing information provided by the senses, but hard to analyze. And even if one knew all the mind's processes, they said, one still would not understand mental performance well; the whole is greater than its parts.

The behaviorist and Gestalt camps debated for years over who best advanced the science. But by around 1960, the debate was stale. It was apparent that behaviorism just was not going to tell us much about how people handle complex functions, such as learning languages and solving problems, because it ignored the mental processes involved. Bothersome too was the behaviorists' denial of the existence of anything like free will—a fact that stirred novelist Arthur Koestler to blast behaviorism as "a monumental triviality that has sent psychology into a modern version of the Dark Ages." Holistic theory, for its part, seemed merely to redescribe mental phenomena, rather than explain them. Psychology was ready for a new approach.

As so often happens in science, a number of psychologists began to see things in a new way at the same time. By the late 1950s, Herbert Simon of Carnegie-Mellon University, George Miller at Harvard (now at Princeton), and others were urging renewed emphasis on cognition. The way to understand mental functioning, they said, was to understand mental processing.

By then, sophisticated research tools were available. The computer offered not only new ways of running tests, but also the possibility of simulating human cognition. Precision instruments improved experimentation. Saul Sternberg of Bell Laboratories was able to show how an alternative to Donders's century-old subtraction method could isolate mental processes without raising the doubts that Donders's tests had: In 1966, he measured operations taking as little as 40 milliseconds—the time required to compare a digit on paper with the mental representation of a digit in the head.

Thus equipped, psychologists were ready to probe cognition deeply. What kinds of things could they learn?

Consider this problem of analogy:

WASHINGTON is to ONE as LINCOLN is to
(a) FIVE (b) TEN (c) FIFTEEN (d) TWENTY

Analogies have long served as a basis for measuring intelligence. Early in this century, the study of mental ability was based chiefly on "factor analysis," a statistical method of relating intelligence-test scores to mental ability. If some students take tests in vocabulary, reading comprehension, figural analogies, and letter-series completions, those who test well (or poorly) in vocabulary might be expected to do the same in reading; ditto for figural analogies and letter series. This suggests that there are underlying verbal and reasoning "factors." Factor analysis has confirmed this.

But factor analysis could not take psychology very far. Tests could not prove one factoral theory of mind to be better than others, or even to be false; in science, a theory is not deemed worthy of attention unless it can be proven wrong if it is wrong. Factor analysis also just did not say much about the processes underlying intelligence: Merely to say that a good analogy-

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solver has strong reasoning ability means little.

Cognitive psychology deals with intelligence by separating reasoning into components. Faced with analogies such as the one above, people perform four main processes before they answer.

Encoding, which translates a stimulus into a mental representation. Here, one might encode the information that WASHINGTON was a president, is on a bank note, and was a war leader.

Inference, which finds a rule that relates the first term of an analogy to the second. The relations between WASHINGTON and ONE: He was the first president, is on a $1 bill, and was a leader in the first major American war.

Mapping, which finds a " higher order" rule relating the two halves of the analogy. Both WASHINGTON and LINCOLN are presidents, faces on bills, and war leaders.

Application, which generates a rule that forms a correct answer and rejects the alternatives. Here, the answer is (a) FIVE, reflecting LINCOLN's image on the $5 bill.

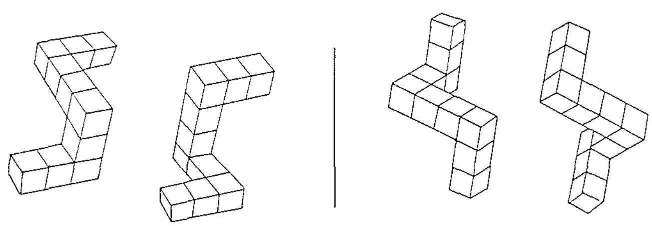
By analyzing processes in this manner, cognitive psychologists have addressed many questions. Some of the problems that have come under study:

- How long does thinking take? The time required by a mental process can be measured. For some verbal analogies, I have found that people tend to spend roughly 54 percent of their time encoding the terms, 12 percent inferring relations, 10 percent mapping higher order relations, seven percent applying relations, and 17 percent in giving the answer. If an analogy is solved in five seconds, 2.7 seconds would be spent in encoding.
- What distinguishes "good" reasoners? In most inductive problems (those without a logically necessary solution), adept reasoners are usually faster than others at answering, but spend more time "up front" deciding what to do; in physics, for instance, experts tend to pause at the beginning of a problem to "represent" it with a diagram or a set of equations. Poorer reasoners are more likely to jump to a conclusion, then reach a dead end. They take a "local" approach, dealing more with the specifics of a problem than with its "global" aspects.
- What is "general" about general intelligence? People who are good at certain mental activities are good at others. Those who read with high comprehension tend to have big vocabularies, to be adept reasoners, to have large stores of general information, and to be articulate. To factor-analytic theorists, this suggested that a "general factor" of intelligence exists. But merely labeling "general" ability does not say what it is.

We have found that the mental processes cited above are used in almost all tests yielding a "general" intelligence factor. Research on analogies shows that while good reasoners tend to be faster than others in inference, mapping, application, and response, they are slower in the first step, encoding. They spend more time getting a clear sense of a problem and thus need less time to solve it. So general intelligence can be explained at least in part in terms of the processes used.

But even more important are the higher order processes that direct the operation. While inference and application, say, are important to general intelligence, even more basic is the "executive" process that decides to use them. Cognitive analysis has thus given us a solid basis for understanding general intelligence, which had been lacking before.

Psychologists are also studying the forms of mental representation on which mental processes act—the forms that information takes in the head. Much of this work grew out of a study published in 1971 by Roger Shepard and Jacqueline Metzler. They showed people pairs of perspective drawings like these:



The test participants had to judge as quickly as possible whether the figures differed only in rotation, or also in terms of a reflection. (In the pair at left, one figure is a mirror image of the other. The pair at right differ only in rotation.)

The key finding was that the time needed to recognize identical pairs depends on how far out of congruence they are. This suggests that people rotate images into congruence in their minds in the same way that objects can be manipulated in the real world. Other studies have shown that the speed of mental rotation—from 320 to 840 degrees per second—depends on the image. Letters and numbers can be rotated faster than figures. Robert V. Kail, Phillip Carter, and James Pellegrino reported in 1980, based on results of tests conducted at the University of Pittsburgh, that the speed with which mental rotation can be performed increases with age, at least from grade three to college. Stephen Kosslyn of Harvard has studied other aspects of imaging. When asked "Which is larger, an elephant or a fly?" people can answer rapidly. But if asked about a cow and a camel, most take longer; the smaller the disparity between the two objects, the slower the response. Other research has shown that in such tests people actually do seem to visualize the two objects and then compare their size.

Though not all psychologists believe that the case for such imaging is proven, most now seem persuaded that people *can* form mental images and move them around.

How Knowledge Is Gained

During the last decade or so, there has been much study of "domain-specific" skill and knowledge—that is, expertise. It is clear that we cannot fully understand excellent performance in any area unless we understand the role of experience.

The key study here was conducted by William Chase and Herbert Simon in 1973, with Master, Class A, and novice chess players. At the time, it was assumed that the experts had a "strategic" advantage: They could plan and "see" more moves ahead than others. But the Chase-Simon tests showed that, in fact, experts plan no further ahead than beginners (the intermediate players did the most forward planning). What marked the Masters was their experience: They could apply recollections of 10,000 or more board positions to their playing.

The findings about memory were also intriguing. The experts were better than others at recalling chess pieces in important board positions, but not at remembering other positions. They were adept at storing *crucial* facts.

From chess, research spread to other areas of expertise: reading, vocabulary, physics, medical diagnosis. Some of the most interesting work has been done on political problem solving by James Voss and his colleagues at the University of Pittsburgh.

For one study, they gathered four kinds of participants: political scientists specializing in the Soviet Union, political scientists with other specialties, political-science students, and chemists with no special knowledge of the Soviet Union. The participants were asked to imagine that they had been made head of the Soviet Ministry of Agriculture and now had to devise a plan to boost low crop production.

The more expertise the participants had, the more time they spent in setting up an initial representation of the problem. The chemists and students devoted the least time to this; the political scientists with non-Soviet expertise, more; and the Soviet specialists, the most of all. The results recall the tendency of

DID INTELLIGENCE END EVOLUTION?

Of all the things that differentiate man from other animals, none has been more important than intelligence, the ability to think and reason. Dolphins, elephants, and other species have developed larger brains. But only man has been able to use mental power to solve even elementary problems such as securing a steady food supply—a task that lesser creatures, with no agriculture, must face over and over again. How did man evolve, in only a few thousand years, from a simple hunter to a masterful being who can deal with complex matters just by, as Isaac Newton said of his approach to questions of physics, "constantly thinking unto them"?

The time and manner of the appearance of intelligence—now commonly viewed as a bundle of discrete mental abilities—is unknown, and may remain so. But in his book *Mind*, published in 1982 when he was at the University of Rochester, experimental psychologist David A. Taylor offers an intriguing hypothesis. He argues that man, in the course of evolution, developed the power to think in small steps that are analogous to those that children are known to take as they acquire the capacity to imagine, to communicate, and finally to reason analytically.

Like the fish, insects, and other lower order beings that first appeared 400 million years ago, a human infant does not think; it reacts instinctively to sensations, such as pain and hunger. Then, at about age two, it develops something known only to mammals and other higher order animals: the capacity to frame mental images, even without input from sight or the other senses. It can imagine things, drawing if necessary only on the information in its brain—a copious library that, by adulthood, can hold more than 500 times as much information as the *Encyclopaedia Britannica*.

This in itself was a useful adaptation: A person could imagine danger in places where he had encountered lions and avoid those places. But development went further: Man became able to imagine lions hunting, dozing, and doing other things. That is, he acquired the ability to produce mental images according to certain patterns. In much the same way that preschool children first begin to "think," humans learned to form sequences of images and to guide them according to learned rules. Research has shown that children do not truly begin to think abstractly until they master language, which trains them to order images in terms of rules. The same precept, Taylor argues, applies to the human race. Only after man acquired

good problem solvers to focus on global, up-front planning, but there is a difference: The chemists could be expected to be excellent problem solvers, but they did not do the global planning that the political scientists did. Yet research on chemists has shown that they do considerable global planning when faced language did he become capable of abstract thought.

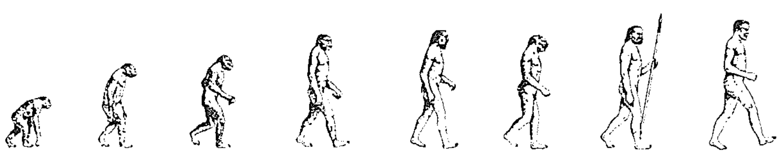
Like imaging, language was useful in itself: It "facilitated vital social practices such as communal living and organized hunting. The fact that it also made thinking possible may have been no more than a serendipity." But thought gave man his "tremendous" edge in the Darwinian fight for dominance in the world.

The final step in the evolution of intelligence, in Taylor's scenario, came when man started to think about thinking itself, including ways to improve it. This may have occurred as recently as the dawn of recorded history. Early writings show no sign of abstract thought or description of mental processes. Stories and myths displaying concern with the ideas and feelings of the characters involved came later—not too long before the Greeks began to study thinking and to lay the foundations of modern logic and philosophy. Thus, abstract thought is a fairly new phenomenon. Says Taylor: "The speed with which intelligence ultimately evolved once the conditions were right is testimony to the tremendous advantages it conveyed in the struggle for survival."

But in endowing man with intelligence, says Taylor, "evolution literally outsmarted itself." Through thought, man has reduced most of the usual threats to survival, such as hunger, disease, and climatic hazards. Result: "There is no longer any selection on the basis of genetic fitness; the weak as well as the strong survive to bear children, and there is no improvement from one generation to the next. In short, evolution appears to be over. . . ."

Biological evolution, that is. It has been replaced by cultural evolution, whose basic unit, "its equivalent of the gene, is the idea."

Among the products of this evolution has been the scientific method, which in a few hundred years has given man vast powers to shape his world. It may even let him "restart" biological evolution, through genetic engineering. In sum, Taylor argues, the advent of intelligence "brought several billion years of biological evolution to a halt," but man has "replaced it with a new form of evolution that is entirely under our control. We are, in effect, the inheritors of evolution. The future is ours to choose."



with problems in their own field.

The findings are convincing: Knowledge of a specialty plays a vital role in problem solving. An understanding of mental processes alone will not show how experts differ from others.

Yet all this has left some cognitive psychologists, including me, with a sense of discomfort. Certainly, experts know more than do novices, which is bound to lead to better performance: Nonexperts cannot spend much time in up-front planning if they have no knowledge of the field to apply. But one might wonder how the experts became experts and why others, with similar experience, did not. Not everyone who plays thousands of chess games will become a Master; not all who read a lot will become expert readers. To understand expertise, then, one must start not with knowledge, but with its acquisition.

Consider vocabulary. The view my collaborator, Janet Powell, and I have taken is that differences in vocabulary relate to differences in abilities to learn new words from their context. Try to define the two uncommon words in this passage:

> Two ill-dressed people—one a tired woman of middle years and the other a tense young man—sat around a fire where the common meal was almost ready. The mother, Tanith, peered at her son through the *oam* of the bubbling stew. It had been a long time since his last *ceilidh*, and Tobar had changed greatly; where once he had seemed all legs and clumsy joints, he now was well-formed. As they ate, Tobar told of his past year, re-creating for Tanith how he had wandered far in his quest to gain the skills he would need to be permitted to rejoin the company. Then, their brief *ceilidh* over, Tobar walked over to touch his mother's arm and left.

How do people figure out unknown words and thus build vocabulary? According to our theory, there are three important ingredients in the recipe for deriving word meanings: contextual clues, mediating variables, and cognitive processes.

Various contextual clues establish that *oam* means steam: We learn that the *oam* rises from a stew and that one can see through it. For *ceilidh* (reunion), we are given two temporal cues: that it had been a long time since Tobar's last *ceilidh* and that it is brief, suggesting that *ceilidhs* are rare and limited in duration.

Mediating variables affect our ability to use contextual cues. For instance, multiple appearances of a word (as with *ceilidh*) usually help us apply our cognitive processes to the cues. Three processes are critical here.

One is "selective encoding," by which one decides what information is relevant for finding a meaning. For *oam*, the cues are that it emanates from a stew, that one can peer through it, and that it is associated with fire. "Selective combination" enables one to assemble the cues. "Selective comparison" enables one to relate new knowledge to old knowledge. Here, one would consider things that relate to the clues—and come up with steam.

Selective comparison is especially critical in remembering new words. Often, one looks up a meaning in a dictionary, then soon forgets it. When one fails to relate a word to information one already has, it is difficult to retrieve later.

We have long known that vocabulary is the best single indicator of intelligence. But this did not make any particular sense in the absence of a theory of how some people acquire large vocabularies, while others do not. We now understand how differences in this, and in intelligence in general, can be traced in part to differences in ability to learn new words and concepts.

The processes of learning are not important only to vocabulary, of course. They also operate in what is known as insight. Consider some famous examples from science.

Alexander Fleming's 1928 discovery of penicillin was an insight of selective coding. In looking at a Petri dish containing a culture that had become moldy, Fleming noticed that bacteria near the mold had been destroyed, presumably by the mold. In essence, Fleming encoded this visual information in a selective way, zero-

Experiments with sound have raised hopes that IQ, now rated by written tests, might be measured by brain-wave activity. The waves triggered by aural stimuli have been found to be large and fast moving in bright people.

ing in on the part of what he saw that was relevant to the discovery of the antibiotic. He had no previously available cues for selective encoding to work on, but he focused on what to him was a new kind of cue—the destruction of the bacteria by the mold.

An example of an insight of selective comparison is Friedrich Kekule's 1865 discovery of the structure of the molecule of benzene fuel. After struggling with the matter to exhaustion, he slept and dreamed of a snake curling back on itself and biting its tail. When he woke up, he realized that the curled snake was a visual metaphor for the core of the molecule, which is a ring of carbon atoms.

Since we cannot probe insights of this caliber in experiments, my colleague Janet Davidson and I have studied more common ones—those needed to solve problems in such books as *Games for the Superintelligent*. Two examples:

▪ 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 of having a pair of the same color?

▪ Water lilies double in area every 24 hours. At summer's start there is one lily on a lake. It takes 60 days for the lake to be covered with lilies. On what day is it half covered?

Both problems require minor insights. People who fail the socks quiz tend to focus on the ratio of black to brown socks, and then to have trouble seeing how to use the information. But the ratio is irrelevant, as is seen by those who selectively encode that the only important facts are that there are two colors, and that a pair of the same color is needed. Even once this is encoded, one must selectively combine the information to realize that the answer is three socks; even if the first two one pulls out are brown and black, the third must make a pair.

The second problem also contains irrelevant information (that there is only one lily at first). It also requires selective combination to figure out that, with the daily doubling, the lake will be half covered on the 59th day—the day before it is fully covered.

Although people differ widely in their insight skills, research that Davidson and I have conducted shows that, to some degree, these skills can be acquired. After some weeks of drill in selective encoding, combination, and comparison, fourth, fifth, and sixth graders do better with simple insight problems.

Cognitive psychologists generally hope to use the knowledge they are gaining to improve people's thinking skills. Ultimately, many of us would like to see the day when what we are learning can be applied not only to everyday problem solving, but also to the thinking that policy-makers do when they make the judgments that affect us all.

Has cognitive psychology delivered on its promise? I believe that it has, in nearly all respects.

First, this science's aim was largely to find out what happens in one's head as one thinks. Though that goal got lost during the focus on behaviorism, research is now providing theories and methods needed for understanding mental processes.

Second, these theories and methods apply to interesting problems, such as the nature of imaging, insight, and vocabulary growth. Initially, with any new paradigm, there is a fear that it will answer only questions that no one cares about. Cognitive psychology has not had this problem.

Third, different aspects of what we are learning are coming together. In its early days, it seemed that the field might offer little more than detailed analyses of isolated mental operations without providing any understanding of how they relate to each other. This has not happened. For example, we have found that the insight processes are basically the same as those of vocabulary acquisition—though it is one thing to use selective encoding in divining the meaning of a new word, and another to apply it in finding that a mold (penicillin) is a potent antibiotic.

But no scientific approach is flawless. There is, in my opinion, one serious problem with cognitive psychology. It is *too* cognitive.

Thought is very much influenced by emotions, motivations, and desires. No matter how finely we analyze the thought processes and the mental representations on which they operate, we will not understand thought in its totality unless we understand how it is driven by, and drives, the noncognitive or "affective" side of human nature—love, pain, belief, will, and so on.

Cognitive scientists sometimes seem reluctant to acknowledge the need to combine their work with an understanding of these "softer" aspects of man's nature. Yet I suspect that we will never understand some of the most important decisions that people make, or the true reasons that they solve problems as they do, unless we probe the noncognitive as well as the cognitive side of the mind. This remains, as the philosopher and psychologist William James said of the nature of personality, "the most puzzling puzzle with which psychology has to deal."