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However, I now have to say that I was conceding too much in my earlier statements of this argument. I was conceding that the computational theory of the mind was at least false. But it now seems to me that it does not reach the level of falsity because it does not have a clear sense. Here is why.

The natural sciences describe features of reality that are intrinsic to the world it exists independently of any observers. Thus, gravitational attraction, photosynthesis, and electromagnetism are all subjects of the natural sciences because they describe intrinsic features of reality. But such features such as being a bathtub, being a nice day for a picnic, being a \$5 bill, or being a chair, are not subjects of the natural sciences because they are not intrinsic features of reality. The phenomena I named—bathtubs, and so on—are physical objects and as physical objects have features that are intrinsic to reality. But the feature of being a bathtub or a \$5 bill exists only relative to observers and users.

Absolutely essential, then, to understanding the nature of the natural sciences is the distinction between those features of reality that are intrinsic and those that are observer-relative. Gravitational attraction is intrinsic. Being a \$5 bill is observer-relative. Now, the really deep objection to computational theories of the mind can be stated quite clearly. Computation does not name an intrinsic feature of reality but is observer-relative and this is because computation is defined in terms of symbol manipulation, but the notion of a *symbol* is not a notion of physics or chemistry. Something is a symbol only if it is used, treated, regarded as a symbol. The Chinese room argument showed that semantics is not intrinsic to syntax. But what this argument shows is that syntax is not intrinsic to physics. There are no purely physical properties that zeros and ones or symbols generally have to determine that they are symbols. Something is a symbol only relative to some observer, user, or agent who assigns a symbolic interpretation to it. So the question, "Is consciousness a computer program?" lacks a clear sense. If it asks, "Can you assign a computational interpretation to those brain processes that are characteristic of consciousness?" the answer is that you can assign a computational interpretation to anything. But if the question asks, "Is consciousness intrinsically computational?" the answer is that nothing is intrinsically computational. Computation exists only relative to some agent or observer who imposes a computational interpretation on some phenomenon. This is an obvious point. I should have seen it 10 years ago, but I did not.

ACKNOWLEDGMENTS

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Creative Cognition: Demystifying Creativity

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Although creative activities are obviously a function of mental processes, creativity has not been typically studied within the contemporary science of cognitive psychology. Part of the reason for this lack of attention to creative thinking is that there has not been a clearly defined paradigm for studying creativity using a cognitive-processing approach. In a recent book (Finke, Ward, & Smith, 1992), however, my colleagues and I established and articulated a creative-cognition paradigm, calling for the study of creativity from the point of view of the mental processes that give rise to creative behavior. Although our original efforts in this area focused on our own laboratory research, there is now a growing number of researchers exploring the cognitive processes and mental structures that underlie creativity (e.g., Smith, Ward, & Finke, in press).

The predominant approach to creativity in psychological research has been psychometric in nature, focusing on creative people and their personality traits. Those individuals who have made the greatest creative contributions in their fields of endeavor have been studied, often in depth, in order to discover what personality factors creative geniuses may have in common. This personality approach may be useful for distinguishing creative people from uncreative ones, but it is not particularly useful in terms of telling us how to think creatively if we do not already do so.

The creative-cognition view states that there are patterns of cognition that set the stage for creative discoveries, patterns that can be found in people in all domains of creative endeavor. This approach focuses not on creative products

or people, but on creative thinking itself. In doing so, we change from the question of who is creative to that of how people think creatively.

Before proceeding further, it will be useful to define what I mean by the term *creativity*, an elusive concept that resists a clear definition. The main problem is that there are few, if any, characteristics that are absolutely necessary for a product to be considered creative. Therefore, I have taken what is known as a "family resemblance" approach, defining creativity as a set of shared properties, none of which are necessary or sufficient for something to be considered creative, but all of which are common in creative products. These shared properties include novelty, imaginativeness, practicality, emergence (new qualities that can emerge when old elements are combined), ambiguity, meaningfulness, incongruity, and divergence (being different from the ordinary). Defined in this way, creativity can be understood without pigeonholing it in any absolute way. It is important to avoid oversimplifying the sometimes paradoxical concept of creativity.

THE PARADOXES OF CREATIVITY

The subject of creativity is riddled with paradoxes. Resolving and clarifying these paradoxes are important for our understanding of creativity. For example, one paradox is that our society needs and treasures creativity, yet at the same time pressures, censors, and shuns those who do not conform to social norms. Conformity does not bring about innovation or novelty, qualities of creative ideas and products. Given the degree of conformity we see in the world, it is not surprising that so few people are considered to be creative. Why, then, in spite of pressure to conform, does our society continue to produce and revere creative people?

It also seems paradoxical that imagination and practicality are the two primary qualities of creative products. These are usually viewed as opposites, rather than as qualities that go together. Imagination so often seems impractical, and practicality seems so unimaginative. How can imaginative ideas be realistic?

Creative thinking may involve special mental processes, such as insight or divergent thinking. Paradoxically, creativity is also thought to be part of our regular "armamentarium" of cognitive abilities, playing an important role in such everyday activities as speaking and dreaming. Does creative thinking involve special skills, or normal everyday ones?

Another paradox is that creativity involves the use of old or expert knowledge, yet it also requires that we do things in new ways. Should we use our prior knowledge in creative thinking, or should we reject it? How are we to distinguish between wisdoms when we are told on the one hand not to fall into a rut in our thinking, yet are also warned to have the sense not to repeat the mistakes of history?

Finally, it seems paradoxical that creative people have been described as having personality traits that are mutually exclusive or contradictory, such as reflectivity and spontaneity, or childlike playfulness and mature wisdom. How is it possible to be both reflective and spontaneous? The answer may be simply

that creative people are reflective at certain times and spontaneous at other times. This apparently simple answer, however, leads to some challenging questions: Is it meaningful to characterize a person as having opposite traits? Are there noncreative people who are also both reflective and spontaneous, but not in a creative way? And most importantly, when are the appropriate times to be reflective and spontaneous if creativity is the desired outcome?

This last question is probably the most useful one, and should be framed in terms of creative processes. An adequate understanding of the process should enable us to address questions such as the stages of creativity in which reflectivity is most needed, and those in which spontaneity is more appropriate. At what point in the process are knowledge and wisdom most important, and when is childlike imagination needed? The approach I have taken is aimed at understanding the processes that underlie creative thinking.

The same cognitive structures and processes involved in noncreative cognition can be used to explain creative thinking. This approach may help to "demystify" creativity, because the mysterious ways in which ideas appear to be created may seem less baffling when expressed in terms that are used to explain everyday thinking. That creative thinking, in one form or another, is not an everyday activity, however, is not a valid assumption. Furthermore, that noncreative cognition is perfectly well understood is equally untenable. The process of demystifying creativity by casting it in terms of cognitive processes and mental structures may help to lift the mystery from some phenomena, but it is unlikely to remove all of the mystery and excitement involved in creative thinking.

Creative cognition involves many complex mental activities, such as formulating and reconceptualizing problems, generating divergent ideas, transcending mental blocks, visualizing, exploring ideas, discovering interesting combinations of ideas, using and adapting one's expert knowledge, discovering insight, and refining ideas. Examples of basic cognitive processes that underlie these activities include encoding, storage and retrieval of information, attention, mental imaging, conceptualization, analogical reasoning and rule-based thinking, and metacognition. Cognitive structures involved in creative thinking include concepts, images, language structures, mental models, schemata, distributed networks, and prototypes. Only a few of these basic underlying cognitive processes and structures will be discussed in the present chapter, but all of them are involved in both creative and noncreative thinking. The goal of creative cognition is not necessarily to describe a certain path to successful creativity, but rather to understand basic cognitive structures and processes well enough to know how to set the stage for creative ideas, discoveries, and products.

THE ROADMAP THEORY OF CREATIVE THINKING

The "roadmap" theory of creative thinking combines a number of conventional theoretical mechanisms into an integrated system that is intended to explain a broad array of phenomena, and resembles other theories in important ways (e.g.,

Newell, Shaw, & Simon, 1962). Although the theory by no means addresses all of the important issues in creative cognition, it nonetheless provides a context for understanding many important aspects of creative thinking. The roadmap theory, as considered here, will incorporate ideas about planful thinking, the logical "tree" structures that planful thinking can produce, a "generative search" process, metacognitive monitoring, fixation, incubation, and insight.

The basic idea of the roadmap theory is to conceive of consciousness as moving from one place to the next, beginning with an initial problem state, and ending with a goal or solution state. The road along which one moves is determined by the plans used to guide thinking. Fixation corresponds to dead-end branchings of the road, and incubation allows escape from dead ends. Several examples, some historical, some from laboratory research, and some from everyday life, will be considered in the context of the roadmap theory.

Plans

A *plan* refers to an abstract cognitive structure that represents a general approach to a situation, and includes rules for manipulating information, making decisions, and guiding behavior. Plans can be general (e.g., how to get through college) or specific (e.g., how to tie your shoes). When a plan is selected for dealing with a situation, the plan's rules are applied until the goals of the plan are successfully attained, whereupon the plan is abandoned. The knowledge state with which one begins is the initial representation of the problem. Given an initial representation of the problem and a plan for dealing with the situation, one can create a roadmap of the possible steps that one might potentially take in carrying out the plan.

The roadmap can be plotted as a hierarchical tree structure, such as the one shown in Fig. 3.1. Thinking in such a structure begins at the top and works its way down, searching for information that will lead, knowledge state by knowledge state, to the anticipated goal of the plan that is guiding one's thinking. The top of the tree structure (labeled *Begin Search* in Fig. 3.1) constitutes the initial representation of a question or problem on which one is working. At each branch in the tree one may choose the next step in one's thinking from the various possibilities offered by the plan. Choosing the next step allows one to descend through the tree structure in search of a target or goal state.

Generative Search

We may commonly think of a search as having a single well-defined goal or target. For example, a math problem such as $845 \times 2509 = ?$ appears to have a very obvious set of rules that guide the problem solver step by step to the single correct solution, using a clearly circumscribed series of rules. The question "How many ys are there in the word *psychology*?" involves a similar direct search path, as well as a clear-cut answer. Not all questions are addressed and answered in

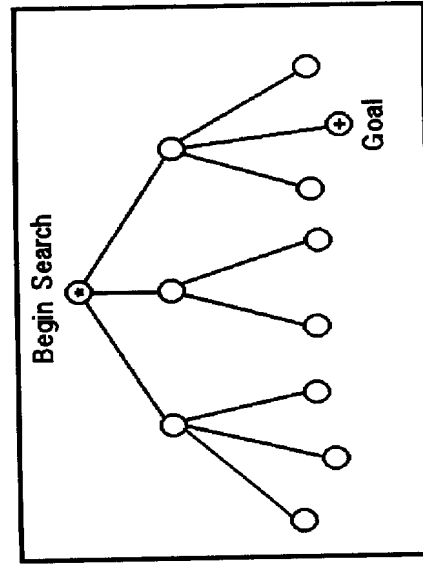


FIG. 3.1. Circles indicate choice points in a hierarchy of possible knowledge states. Movement from one knowledge state to another is done according to the rules of the plan guiding the search. The generative search typically begins at the top of the map and works its way down, step-by-step, in search of a goal.

such a clear-cut fashion. For example, "What should you serve for dinner when you have important guests?" has many possible considerations, and many possible answers, some better than others.

The exploration of one's knowledge in search of ideas and information that may lead to a solution is an open-ended process that I refer to as a *generative search*. At each choice point one can generate many possible *next steps* to pursue. Any step may appear to be a promising lead or a useless dead end. As you generate and gather information, you arrive at potential goals, targets, and solutions to the original problem. Important to this theory is the fact that the targets and solutions and goals being sought are not explicitly stored facts that reside passively in memory, with the goal of the problem solver being merely to find answers that are already there. Goal states are achieved by being constructed, step-by-step, using not only preexisting knowledge, but also new ideas that emerge during a generative search from combinations of existing knowledge. This generative, constructive approach to how knowledge is used thus explains how the same cognitive system can carry out both narrowly defined convergent tasks, such as math problems, and broad, ill-defined problems, including those that require creative solutions.

Monitoring

Metacognitive *monitoring*, like introspection, refers to the act of attending to one's own thoughts. In the roadmap theory presented here, self-monitoring is an important element for determining the directions taken by the generative search. At each branching, or choice point, the thought process may proceed either in

ways that fulfill the goals and constraints of one's current guiding plan, or in directions that are inappropriate for reaching an optimal solution. As thinking continues from one knowledge state to the next, the appropriateness of one's choices can be gauged in terms of the number of subgoals and constraints that become satisfied along the way. The more subgoals and constraints that become satisfied when thinking takes a particular direction, the closer one feels to the final goal, and the more likely one is to persist in that direction. This part of the thought process refers to *verification*, or verifying that one's mental work has been appropriate.

Monitoring one's thinking is very useful for keeping problem solving on track, particularly for tasks that are highly familiar. A potential drawback of the verification process, however, is that partial verification of one's thinking may guide one blindly down a path that cannot lead to a solution. Such events refer to *dead-end branchings*, and will be discussed at length to describe their important role in creative cognition.

Fixation: Dead-End Branchings

Fixation in problem solving refers to getting stuck in one's work on a problem. More generally, the term has been used to refer to any of a number of ways that remembering, solving problems, or creative thinking can be at least momentarily blocked (e.g., Smith & Blankenship, 1991). The simplest type of cognitive block is *interference* in memory, also known as *response competition*. When two different memories become learned, the two corresponding responses can be thought of as competing with each other when an attempt is made to retrieve one of the memories. One memory (to be called the *blocker*) can intrude upon consciousness, blocking a similar memory (the *target* of the search) from being retrieved. When the blocker is stronger than the target, it wins the competition, causing a *memory block*.

In terms of the roadmap theory, interference occurs when the direction of one's thinking leads to retrieval of a blocker, rather than to the planned target of one's search (Fig. 3.2). A turn in one's cognitive roadmap toward a blocked pathway is a *dead end*, a point from which one cannot discover a correct target without abandoning the blocked path. The ease with which one can abandon a dead end depends on how strong a blocker is, and how far one has taken a blocked path; it is not always easy to tell at which point one has taken a wrong turn on one's mental highway.

A number of factors can contribute to the cognitive fixation that can occur when one has taken a dead-end path. Two classes of factors that will be considered here are *typical thinking* and *recent experience*. Typical thinking is the result of long-term experience, caused by repeated use of parts of the mental roadmap in habitual ways. The major problems with typical thinking when new, creative ideas are sought are that thinking can proceed automatically, based on unfounded,

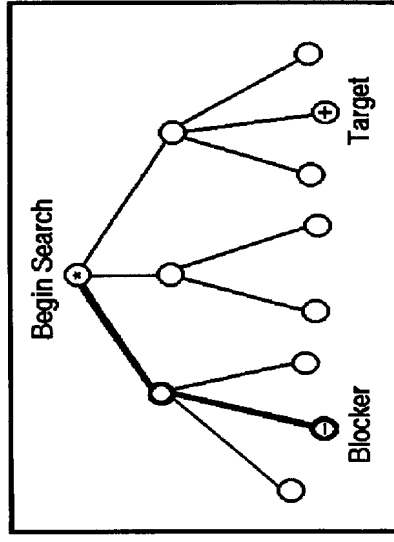


FIG. 3.2. Heavier lines indicate stronger or likelier paths caused by recency or frequency of use. A search may be diverted down a dead end if a blocker is typical or has been recently encountered.

implicit assumptions, and that old paths are unlikely to lead to new ideas. Recent experiences can make inappropriate ideas at least temporarily stronger. Although recent encounters with blockers may be less of a problem than typical thinking in many situations that require creative thinking, recency nonetheless provides a means of manipulating and studying mental blocking in experimental settings.

One type of typical thinking that leads to dead-end paths is called *functional fixity* (e.g., Maier, 1931). This term refers to a difficulty in seeing an object as being useful for reasons other than the ways the object is typically used. Maier's now classic "two-string" problem could be solved only by seeing that a pair of pliers could be used as a weight for a pendulum, rather than for their more typical purpose.

One of my favorite examples of a real-life problem involving functional fixity happened to a former professor of mine who started up her car one morning only to discover that her radiator cap was missing. A negligent mechanic had failed to replace the cap the previous day when her car had been repaired. She sensibly decided to drive back to the garage to retrieve the missing radiator cap, and to offer a few choice words to the errant mechanic. Even more sensibly, she decided to get something for a temporary replacement to keep the radiator from disgorging its contents while she drove to the garage. What was she to use as a temporary replacement for a radiator cap?

I have posed this problem to thousands of students, and their answers almost always show a clear pattern of functional fixity. The first answers likely to be offered are to use other objects used to cap things in automobiles, such as the gas cap or oil cap. The functional fixity shown here is very specific, focusing on other very similar objects. These initial ideas must be discarded on the basis that even if one of those caps did fit, another cap would still be needed to replace

the replacement. Students then move on to other materials in the home that are typically used to close off things, such as saran wrap, aluminum foil, or a rag. Again, typical, functionally fixated thinking fails in this case because none of these typical materials could withstand the radiator heat and pressure, even for a brief time.

The professor's solution was inspired, and surpassed or escaped functional fixity; she grabbed a large potato from the vegetable bin and jammed it into the opening of the radiator—one size fits all! Her solution was creative and elegant (and inexpensive). The "potato plug" worked, an idea that required novel thinking, unconstrained by the mental dead ends offered by typical thinking, allowing her to drive safely to the garage.

The thinking involved in this situation can be illustrated by the mental roadmap in Fig. 3.3. The likeliest first steps involve either alternative automobile parts or common household materials used for wrapping. Typical thinking thus begins with the very first step, taking dead-end turns on the mental path. Although vegetables typically function in capacities other than auto parts, the potato had qualities (e.g., size, composition, availability) that made it an ideal temporary radiator cap. Sometimes, even brief mental excursions can lead to surprising ideas.

Typical thinking can involve a number of different types of trap for the problem solver, some of them due to inappropriate implicit assumptions. One such trap is illustrated by the following popular riddle:

It was a dark and stormy night when a man and his son drove around Dead Man Curve. The car suddenly lost traction and skidded into a great oak tree, killing the man instantly, and throwing the boy from the car. An ambulance arrived quickly and sped the boy to the emergency room for surgery. Moments after the boy was wheeled into the operating room, the surgeon emerged, hands trembling, and said, "I cannot operate on this boy. He is my son!" How is this possible?

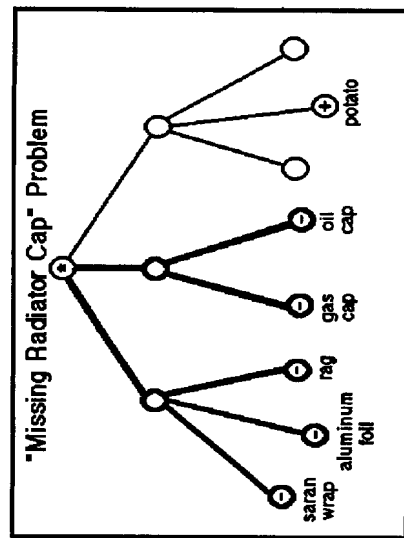


FIG. 3.3. Two entire branches of this roadmap represent typical directions of thinking that lead down dead ends in the radiator-cap problem.

3. CREATIVE COGNITION

When I pose this problem to my students, the first solutions they try are that the boy was the dead father's adopted son and the surgeon's biological son (or vice versa), the man is the boy's grandfather, the man is a minister (a type of father), or that the mother lied to her husband all those long years ago about who the real father was. These incorrect attempts are diagrammed in Fig. 3.4, which shows the dead-end branchings that solvers usually take. Importantly, all of the inappropriate paths bear the implicit assumption that surgeons are men. In this case, an unwarranted sex-role stereotype prevents people from seeing the obvious solution; the surgeon is his mother.

How obvious should the solution be if not for sex-role stereotypes? See for yourself as you try this slightly altered version of the surgeon problem:

It was a dark and stormy night when a woman and her son drove around Dead Man Curve. The car suddenly lost traction and skidded into a great oak tree, killing the woman instantly, and throwing the boy from the car. An ambulance arrived quickly and sped the boy to the emergency room for surgery. Moments after the boy was wheeled into the operating room, the surgeon emerged, hands trembling, and said, "I cannot operate on this boy. He is my son!" How is this possible?

The surgeon is obviously the boy's father, a man. No one even considers this to be a riddle, because it doesn't require altering an unconscious stereotype to solve it.

Recent experience can also strengthen paths that lead to blockers. An important consequence of this is that recent experience can be experimentally manipulated and researched, whereas the typicality of a particular train of thought varies greatly among people. Different people have different stereotypes, and they also differ in terms of other implicit assumptions that they may make. These differences make typical thinking difficult to study, because the experimenter cannot

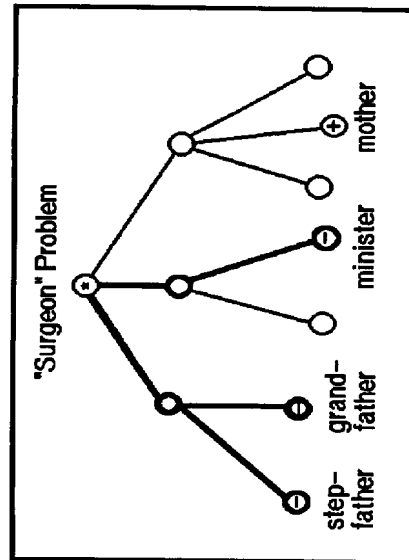


FIG. 3.4. A prejudicial sex-role stereotype, that surgeons are men, prevents thinking from taking the appropriate path to the otherwise obvious solution in the surgeon problem; the surgeon is the boy's mother.

control that variable. Recent experience, however, can be controlled, and therefore has proven a valuable tool for research on fixation and related mental blocks.

The first researcher to capitalize upon the hypothesis that recent experience can block solutions to problems was Luchins (e.g., Luchins & Luchins, 1970). His now famous water jar problem demonstrated the importance of mental set, what he referred to as *mechanization* of thought. The task in which water jar problems are given involves the subject solving a long series of similar problems that require mathematical solutions. When subjects discover that a single, moderately complex algorithm (B - A - 2C) can be repeatedly used to solve every problem, they typically speed up work, solving each one very quickly. At one point in the sequence, a problem is inserted that cannot be solved with the recently discovered algorithm, but can be solved by an extremely simple algorithm (A + B). Subjects typically get stuck when they get to the special problem, failing to see the obvious solution because of their recent problem-solving experience. The mental set found in solving a series of Luchins' water jar problems can be explained as the result of a temporary strengthening of a blocker's (B - A - 2C) path.

I have also conducted numerous experimental studies on the subject of fixation in which blocks are introduced in the laboratory by exposing subjects beforehand to blockers. My studies have used a broad variety of cognitive tasks and materials, a few of which I will presently describe. These studies all show that recent experiences can cause fixation in memory, problem solving, and creative thinking.

One set of experiments to be described used Remote Associates Test (RAT) problems (Smith & Blankenship, 1991), which are commonly used to test creative thinking. For RAT problems one must find a single word (the solution) that is strongly related to each of three test words that are given. For example, for the RAT problem "CAR-SHOE-TOP" the solution is "box," because it makes a two-word phrase or a compound word with each of the three test words: "box-CAR," "SHOE-box," and "box-TOP." Other examples of RAT problems are shown in Table 3.1.

TABLE 3.1
Sample RAT Problems, Solutions, and Blockers

RAT Problems		Solution	Blocker
ARM	COAL	STOP	rest
BALL	STORM	WHITE	cloud
SHIP	PARKING	SUIT	jump
DECK	SCOTCH	RECORDER	flight
APPLE	HOUSE	FAMILY	green
CAT	SLEEP	BOARD	black

Note: Every solution word makes a two-word phrase or compound word with each of the three problem words. Every blocker makes a phrase with two of the three problem words.

The reason that RAT problems are considered to test an important aspect of creative thinking is that they require the problem solver to engage in a type of atypical thinking referred to as *remote association* (e.g., Mednick, 1962). For remote association one must think not of common associates of the test words, but of unusual ones, because there is one unusual associate in common for all three test words. For example, common associates of the RAT word "ARM" might be "leg" or "hand"; common associates of "COAL" are "mine" and "black"; and common associates for "STOP" are "sign" and "bus." A remote associate of all three test words, ARM, COAL, and STOP, is "pit," which makes the combinations "ARM-pit," "COAL-pit," and "pit-STOP."

Blocker words were found that were not quite correct answers; each blocker makes a two-word phrase or compound word with only two of the three test words. For example, the blocker word "horn" fits with two of the RAT words from the "CAR-SHOE-TOP" example ("CAR-horn" and "SHOE-horn"), but does not fit with the third RAT word (TOP). In our experiments on fixation effects, we introduced the blocker words in a task that was ostensibly unrelated to the later tasks in the experiment (i.e., the RAT problems). For example, the blockers were sometimes used as stimuli in what was called a test of short-term memory (e.g., Smith & Schumacher, 1992).

We have repeatedly found that recent viewing of blocker words impedes performance on RAT problems (Smith & Blankenship, 1991; Smith & Schumacher, 1992). Furthermore, even when subjects who have seen blockers are able to solve the RAT problems, they take considerably more time in doing so, as compared to control-group subjects who see unrelated words rather than blockers in their incidental "short-term memory" task. Figure 3.5 depicts this fixation or blocking in a RAT problem. The mental path to "horn" is momentarily strengthened, relative to the path that leads to the correct answer, "box."

Although the RAT tests remote association, it is not intended as a test that requires subjects to be highly imaginative. An open-ended activity, referred to as a *creative generation* task, examines more creative, imaginative thinking (e.g., Smith, Ward, & Schumacher, 1993). In this task, subjects are asked to create as many new objects as they can for a given category. For example, Smith et al. asked subjects to sketch and label as many new ideas as they could for toys, or to create new animals for an imaginary inhabited planet similar to Earth. Although not all the college students in the experiments were creative, a large number of them came up with fascinating and creative ideas in a brief experimental session.

Recent experiences with novel toys or imaginary animals were experimentally introduced by Smith et al. (1993) in the form of examples. Some subjects saw three examples of imaginary animals, each of which happened to have four legs, antennae, and a tail, or three examples of imaginary toys, each of which used a ball, electronics, and required a high degree of physical activity. Certainly, not all imaginary creatures and toys must have these features. Smith et al. found that

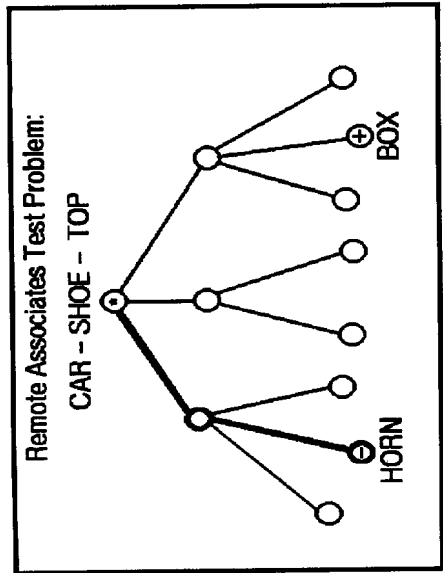


FIG. 3.5. Recent experience with the blocker word "horn" draws thinking down an inappropriate path in the "CAR-SHOE-TOP" Remote Associates Test problem. The appropriateness of both the phrases "CAR-horn" and "SHOE-horn" make the dead end even more compelling. The correct target, "box," is weaker if it has not been recently seen.

viewing the examples fixated subjects, constraining their creative thinking in this generation task. Those who saw examples were far more likely to include the example features in their sketches than subjects who had seen no examples. The conformity shown by subjects who had seen examples appeared to be involuntary, and was every bit as strong an effect even when subjects were explicitly instructed to generate ideas that were as different as possible from the examples.

An even more realistic creative-generation task was used by Jansson and Smith (1991), who had engineering designers generate novel designs for specified creative-design problems. For example, designers in one experiment were asked to "design a measuring cup that blind people can use," or, in another, to "design an inexpensive, spillproof coffee cup that does not use a straw or a mouthpiece." Half of the designers were shown examples, and half were not. The examples often contained obvious design flaws. For example, the example shown for the spillproof coffee cup had a mouthpiece, which was specifically forbidden, because hot coffee drunk through a mouthpiece without taking in air would scald one's mouth. Nonetheless, more than 50% of the students who saw an example created designs of cups with mouthpieces, even though they were expressly ruled out in the instructions. Only 11% of the control subjects committed the same error in their designs.

This constraining of creative thinking, termed *design fixation* by Jansson and Smith, again can be explained by the roadmap theory. In Fig. 3.6 the mental path leading to ideas for spillproof cups with mouthpieces is shown to be temporarily strengthened by the recent experience with the fixating example. Control subjects are not similarly constrained, generating many more designs of spillproof cups without mouthpieces.

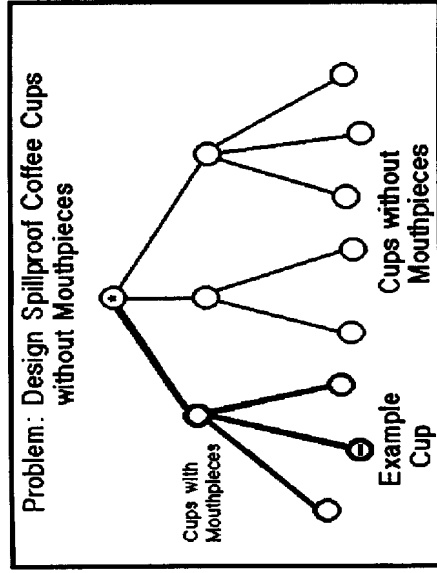


FIG. 3.6. Design fixation results from temporary strengthening of mental paths that lead to designs with mouthpieces.

RESOLVING MENTAL BLOCKS

So far, I have focused on fixation and blocking, situations that prevent discovery of solutions along one's mental highway. I now turn to the issue of resolving impasses, escaping from dead-end branchings of the road along which one is thinking.

The notion of *incubation effects* has been popular since Wallas (1926) proposed it as a stage of problem solving. The idea of incubation is that after initial attempts at creative problem solving lead to impasses, it may be beneficial to put the problem aside rather than continuing to work at it. If work is interrupted, then an insightful idea may pop into one's head when one returns later to the problem, or even while one is engaged in an unrelated activity. Anecdotally, people often discover this pattern of incubation in their own everyday lives. Furthermore, famous historical examples abound in which sudden insights burst into scientists' minds unexpectedly, while they were engaged in unrelated activities (e.g., Archimedes' discovery of the displacement principle while at the baths; Kekulé's discovery of the benzene ring as he dozed in a chair).

Unfortunately, several factors have contributed to the notion that sudden-insight experiences after incubation periods are caused by mysterious, unconscious forces that labor invisibly at difficult problems while the conscious mind, which was too stupid to solve the problem in the first place, relaxes on vacation. One contributing factor is that famous, insightful scientists may not be good cognitive psychologists, and therefore attribute their incubated insights to the wrong causes. A second factor is that the name that has been assigned to the phenomenon, *incubation*, is a metaphor that suggests something that develops invisibly, and then hatches suddenly, without much warning. Just because the phenomenon has the name

incubation, however, does not mean that invisible-idea development occurs in the unconscious mind. Finally, a factor that has contributed to this mysterious view of incubation is the surprising dearth of laboratory evidence of the phenomenon; without empirical evidence, inappropriate assumptions are not easily rejected.

The theory of incubation and insight that I endorse does not assume unconscious processes, and is supported by ample empirical evidence (e.g., Smith, 1994; Smith & Blankenship, 1989, 1991; Smith et al., in press). This theory states that incubation and subsequent insight experiences begin with cognitive impasses, as illustrated in the roadmap theory in this chapter. An impasse occurs when one's mental set yields too strong a tendency to take a dead-end branching of a cognitive path. Because the mental set that leads to a dead end can be caused by recent experience or typical thinking, then the way to avoid the dead end is to approach the problem with a different mental set, one that is less likely to lead into the same trap. Incubation, then, has its beneficial effect by: (a) making one's initial mental set less recent, and (b) taking one into different contexts that are associated with different mental sets.

Evidence that leaving one's typical setting enhances incubation and insight comes from historical examples. Archimedes and Kekulé had their insights while away from their work. Poincaré's famous mathematical insight occurred while he was stepping onto a bus, and Nobel laureate Kary Mullis got the idea of polymerase chain reaction while on a midnight drive. Ample evidence that making blocker experiences less recent facilitates incubation comes from laboratory studies that show how performance recovers after blockers are shown if retests are delayed (Smith & Blankenship, 1989, 1991; Smith & Schumacher, 1992; Smith & Vela, 1991).

This view of incubation and insight that involves altered mental sets is thus demystified to some degree. The idea that one's mental set changes over time or in new contexts fits not only with personal experience, but with historical examples as well. The theory is consistent with laboratory evidence on incubation effects, as well as studies that show the suddenness of insight experiences (e.g., Metcalfe, 1986; Metcalfe & Weibe, 1987). The logic of the theory does not depend upon the idea of mysterious, invisible, unconscious processes, of which we have neither empirical nor experiential evidence. Thus, an important aspect of creativity is neither glorified nor denied, but explained in clear and verifiable terms.

SUMMARY

In the present chapter I have outlined and illustrated an approach for demystifying creativity that involves careful examination and research on the mental processes that are involved in creative thinking. The roadmap theory provides a context for understanding a broad range of phenomena, from everyday thinking and remembering to the creative phenomena of fixation, incubation, and insight. As

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such, the theory can help to resolve some of the paradoxes of creativity noted at the beginning of this chapter.

For example, whether fixation, incubation, and insight involve special processes can be addressed. These phenomena have been explained herein as special results of thinking within a very understandable cognitive system. The creative-cognition approach has now led to specific experimental findings of these phenomena under conditions predicted by the theory (e.g., Smith & Blankenship, 1991; Smith et al., 1993; Smith & Vela, 1991).

Another paradox, that creative thinking must both use and reject old knowledge, is also understandable from the creative-cognition point of view. At least some expert knowledge must be present if one is to carry out a successful generative search. One must monitor, however, for times when the knowledge used to guide a search is inappropriate, and reformulate problems when such impasses are reached. Should our classrooms emphasize knowledge or creativity? Clearly, they must do both. True creativity is not possible without knowledge, yet without knowing how to use one's knowledge creatively, one can solve only old types of problems.

An important implication of the position taken up in this chapter is that creative thinking is understandable and describable in terms of cognition, and therefore can be learned. In the past, researchers have focused on testing and identifying which individuals are creative. The creative-cognition approach implies that nearly anyone with an appropriate knowledge base can generate creative ideas if they learn to use that knowledge in creative ways.

The present chapter by no means covers the range of ideas being researched in creative cognition (see Finke et al., 1992; Smith et al., in press). A brief list of other topics in creative cognition includes:

1. Conceptualization and conceptual combination, including emergent properties, and reconceptualization
2. Analogical reasoning, a conceptual way of generalizing old knowledge to new situations
3. Visualization, both of abstract relations and concrete forms
4. Computational models (usually computer simulations) of creative cognition.

As can be seen from this list, the roadmap theory only scratches the surface of research in creative cognition.

REMYSTIFYING CREATIVE THINKING

Understanding aspects of creative thinking demystifies the phenomenon in certain respects, but it also leads to new questions. How do people know when to persist on a mental road, and when to abandon the path? If blocks occur beyond our

awareness, how can we learn to detect them? Once we have successfully abandoned a dead end, how do we find a more appropriate path? A creative-cognition approach helps us understand old questions about creativity, but in the process, provides new mysteries to be explored. In a sense, the business of demystifying creativity has the additional effect of remystifying it, guiding our future exploration of creative thinking.

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Creating Contexts for Community-Based Problem Solving: The Jasper Challenge Series

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At the present time there are calls from within and outside the educational community to reconceptualize learning goals for students, as well as the roles teachers play in this learning (NCTM, 1989). No longer are the basics defined as reading, writing, and arithmetic, but as the ability to think critically, reason, reflect, engage in argumentation, and develop the capacity for independent learning. These new goals constitute what has been termed the "thinking curriculum" (Resnick & Klopfer, 1989) and are being espoused not only by educators but also by members of the business community who recognize the need for workers who can be independent learners and decision makers (Senge, 1990).¹

These learning goals call for dramatic changes in our current educational environments. For the past several years, the Cognition and Technology Group at Vanderbilt (CTGV), a group of researchers at Vanderbilt's Learning Technology Center, has been experimenting with technologies that can help facilitate the process of moving toward thinking curricula. This chapter continues a discussion we began earlier in which we traced the evolution of our thinking about the role cognitive psychology might play in implementing such approaches to instruction. Our discussion in that chapter focused on three different models of the role of

¹As is evident from the contents of this chapter the Learning Technology Center is a multidisciplinary and highly collaborative environment. We point out the many advantages of this organization in this chapter. One of the consequences of such an organization is that many have ownership over a particular project. This multiownership is reflected in the large number of authors listed on this paper.