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# 3 Demystification of Cognitive Insight: Opportunistic Assimilation and the Prepared-Mind Perspective

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Insight may occur in many diverse forms, ranging from the relatively mundane to the immensely profound. On the mundane level, there are examples such as the following (modified from Mosler, 1977):

Two men who were walking through a desert stopped when they saw an unusual thing. They had discovered a third man lying on a stretch of sand, and he was dead. They noticed the dead man had carried a small pack with fresh food and water still in it. The dead man also had a larger pack on his back, and on his index finger was a large ring. The two men pondered the cause of the third man's death, but they could not explain it, and so they proceeded onward.

Later, while going along, one of the original two men accidently dropped a handkerchief that he had taken from his pocket to wipe his brow. Then, he suddenly realized how the third man probably died. Overhead, the third man's parachute had broken, and he had fallen precipitously to earth.

Similarly, but on a more profound level, there are examples such as Isaac Newton's legendary discovery of the universal law of gravitation. As the legend goes, Newton went for a trip one autumn in the English countryside. During his sojourn there, he happened to notice an apple fall from a tree. On seeing this, it suddenly occurred to him that, in essence, the moon is like an apple being pulled toward Earth, after which Newton proceeded to formulate his gravitational law and deduce its many physical consequences.

The diversity of such examples, spanning Newton's apple and the man who fell to earth, raises many intriguing questions. What exactly is the nature of insight? Through what type(s) of mental process is insight achieved? How have Newton and other special individuals like him attained it? Must minds such as Newton's remain forever shrouded in mystery, or can they be studied scienthe correct lines must extend outside the periphery of the dots' rectangular array. What Weisberg and Alba (1981a) found, however, was that subjects seldom solved the nine-dot problem through a quantum leap of insight springing from this realization. Even when subjects received explicit hints that gave the allegedly necessary insight away, they still often needed many more tries at drawing the lines before reaching a successful solution, and progress toward success appeared to occur only gradually.

From these and other related results, Weisberg and Alba concluded that even in attempts to solve prototypical insight problems, business as usual may provide the best view of what actually happens in people's minds. More specifically, these investigators argued that "spontaneous reorganization of experience does not occur during problem solving" (Weisberg & Alba, 1982, p. 326), and "the terms 'fixation' and 'insight' are not useful in describing the processes involved in the solution of these problems...." (Weisberg & Alba, 1981a, p. 169). Instead, they proposed that:

> [S]olution behavior ... can be understood in a straightforward manner: People apply their knowledge to new problems, and if their knowledge is not directly useful, they try to produce something new that will solve the problem through a straightforward extension of what they know. No exotic processes, such as hidden insight, are involved. (Weisberg & Alba, 1981a, p. 189)
>
> Basically, this viewpoint argues that presentation of a problem serves as a cue to retrieve relevant information from memory. Any information that is retrieved then serves as the basis for solution attempts. In this way, it is assumed that problem solving begins with relevant past experience.... A truly novel solution can evolve [through repeated mismatch-driven memory searches] as the problem solver tries to make old knowledge fit the new situation. (Weisberg & Alba, 1981a, p. 171)

If this is so, then problem solving would have much the same appearance as conventional trial-and-error learning, hypothesis testing, and so forth, of which ordinary people and other mammals are usually capable.

In this regard, Weisberg and Alba are not alone. The business-as-usual perspective has also been espoused by a number of other researchers (e.g., Saugstad & Raaheim, 1957; Weaver & Madden, 1949) because of apparent failures to observe spontaneous insightful problem solving in laboratory situations. Some theoreticians



who formulate computational models of problem solving have likewise tended toward business as usual by accounting for Gestalt restructuring through standard information-processing mechanisms (e.g., Ohlsson, 1984a, 1984b; Kaplan & Simon, 1990; Keane, 1989). Under their models, the restructuring of a problematic mental representation stems from retrieval processes that search semantic memory for relevant concepts. Difficulties associated with reaching a successful solution are then attributed to a failure in accessing the right solution plans from memory. For example, in his modeling, Keane (1989) has assumed that memory contains all the explicit plans needed to solve given problems; with this assumption, restructuring of a problem would be difficult only because of uncertainties about exactly when to restructure and how to search for a different representation.

The perspective offered by business as usual should not be oversold, however. Contrary to results from the experiments mentioned earlier (viz. Saugstad & Raaheim, 1957; Weaver & Madden, 1949; Weisberg & Alba, 1981a), some laboratory studies of problem solving have revealed apparent intuitive quantum leaps of insight on the part of people who had no prior expectations of impending successful solutions (e.g., Metcalfe & Weib, 1987, Dominowski, 1981). Moreover, many notable observers of insightful performance, having witnessed and contemplated extreme forms of it on a firsthand basis, would strongly dispute whether matters of the mind are always so straightforward and amenable to analyses in terms of memory search, computer metaphors, and other such theoretical formalisms. Doubts of this latter sort appear, among other places, in the book *Logic of Scientific Discovery* by the famous philosopher of science, Karl Popper (1968; cited in Bowers et al., 1990, p. 94), who warned, "There is no such thing as a logical method of having new ideas, or a logical reconstruction of this process. My view may be expressed by saying that every discovery contains 'an irrational element,' or 'a creative intuition.'"

### The Wizard Merlin Perspective

Reflecting and magnifying Popper's (1968) personal view, there is the Wizard Merlin perspective on insight. From the vantage point of those who hold it, true insight does indeed occur, and the resulting products may be awesomely spectacular. In the spirit of its namesake, the mythical wizard Merlin, this perspective also embodies a claim that true insight stems from seemingly supernatural mental powers, which are possessed by only a few most gifted individuals, whose minds are neither capable of being mimicked nor open to scientific explanation.

The basis for the Wizard Merlin perspective comes from cases such as that of Richard Feynman, the renowned American physicist who is reputed to have been an intellectual magician and scientific genius of the highest caliber (Gleick, 1992). Starting in his early twenties at the Manhattan Project, which built the first atomic bomb, and continuing throughout the rest of his life, Feynman made myriad insightful contributions to our understanding of the atom's structure and component particles. Among his favorite forms of visualization were so-called Feynman diagrams (figure 3.2), which depict fundamental interactions among electrons and electromagnetic radiation. Using such representational devices, Feynman's research provided penetrating insights into nuclear fission, quantum electrodynamics, superfluidity, and radioactive decay (e.g., Feynman, 1985). Feynman was also instrumental in identifying the crucial component (an excessively cold, shrunken, brittle rubber O-ring) whose failure caused the spectacular destruction of the space shuttle *Challenger* in January 1986.

Because of Feynman's many achievements and the apparent ease with which he attained them, other scientists and mathematicians—outstanding researchers in their own right—marveled at his virtuosity and perpetuated accounts of it, some amusing and others more reverent. On the amusing side, we have the following anecdote, which also involves the Nobel laureate and occasional Feynman collaborator, Murray Gell-Mann (Gleick, 1992, p. 315):

> A physicist studying quantum field theory with Murray Gell-Mann at the California Institute of Technology in the 1950's, before standard texts have become available, discovers unpublished lecture notes by Richard Feynman.... He asks Gell-Mann about them. Gell-Mann says, "No, Dick's methods are not the same as the methods used here." The student asks, "Well, what are Feynman's methods?" Gell-Mann leans coyly against the blackboard and says, "Dick's method is this. You write down the problem. You think very hard." (Gell-Mann shuts his eyes and presses his knuckles periodically to his forehead.) "Then you write down the answer."



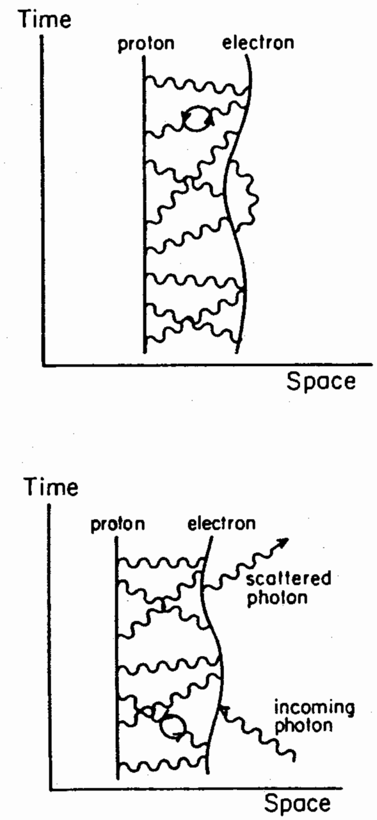


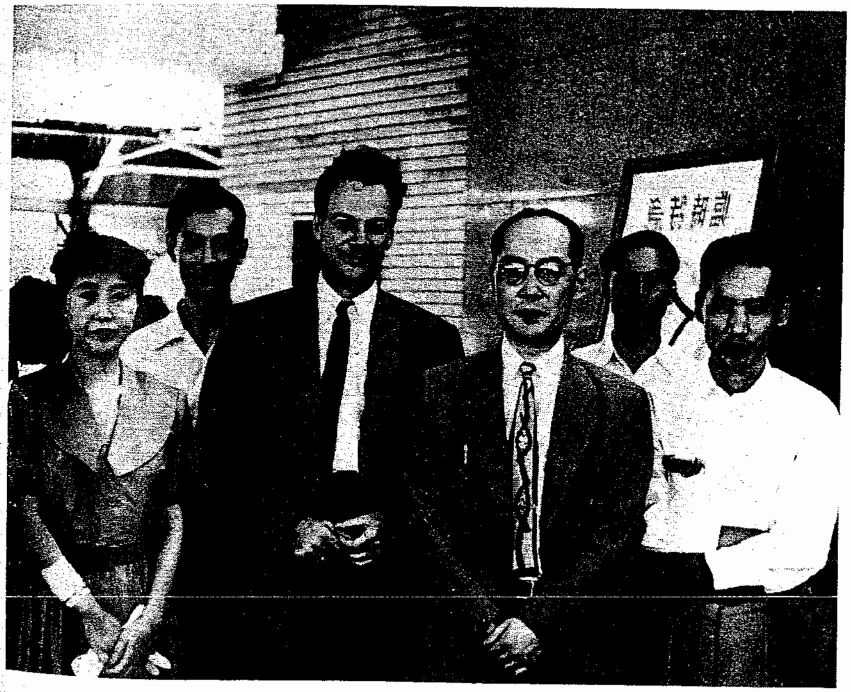

**Figure 3.2**
A Feynman diagram of the type used by Richard Feynman to depict and analyze interactions between elementary charged particles and quantum fields of electromagnetic radiation. (Reprinted with permission from Feynman, R.P., *QED*. Copyright © 1985 by Princeton University Press.)

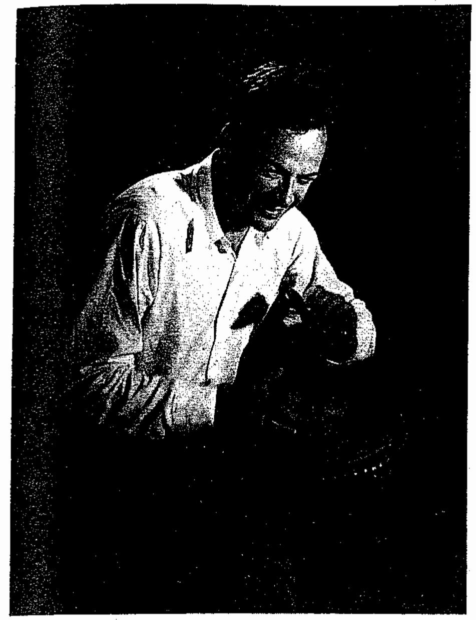
A further compelling expression of the awe in which Feynman was held by his contemporaries came from Mark Kac, another eminent Feynman collaborator. In Kac's words (Gleick, 1992, pp. 10–11):

> There are two kinds of geniuses, the "ordinary" and the "magicians." An ordinary genius is a fellow that you and I would be just as good as, if we

## Photos of Richard Feynman reprinted from *Genius: The Life and Science of Richard Feynman* by James Gleick. New York: Random House, 1992.

Feynman and Hideki Yukawa in Kyōto, 1956: Feynman presented his theory of superfluidity, the strange, frictionless behavior of liquid helium—quantum mechanics writ large.





Playing the bongos: "*On the infrequent occasions when I have been called upon in a formal place to play the bongo drums, the introducer never seems to find it necessary to mention that I also do theoretical physics.*"

Talking with a student as Murray Gell-Mann looks on: "*Murray's mask was a man of great culture ... Dick's mask was Mr. Natural—just a little boy from the country that could see through things the city slickers can't.*"

were only many times better. There is no mystery as to how his mind works. Once we understand what they [*sic*] have done, we feel certain that we, too, could have done it. It is different with magicians. They are, to use mathematical jargon, in the orthogonal complement of where we are and the working of their minds is for all intents and purposes incomprehensible. Even after we understand what they have done, the process by which they have done it is completely dark. They seldom, if ever, have students because they cannot be emulated and it must be terribly frustrating for a brilliant young mind to cope with the mysterious ways in which the magician's mind works. Richard Feynman is a magician of the highest caliber.

Coming from such esteemed sources, these homages to Feynman bear both good and bad tidings to us. On the positive side, their conviction attests strongly to the seeming reality of insight as a distinct, unique, and impressive mental feat worthy of further investigation; they do not make insight out to be just business as usual. Were the Wizard Merlin perspective accurate, it could likewise account for why some experimental psychologists (e.g., Weisberg & Alba, 1981a) have encountered difficulty in observing quantum leaps of insight by mere college students during problem-solving attempts; maybe only geniuses such as Feynman, with a bent toward Feynman diagrams (see figure 3.2), have what it takes to solve nine-dot problems insightfully! On the negative side, however, this prospect would bode ill for our analyzing and thoroughly understanding the mental processes that mediate true insight. If we accept the Wizard Merlin perspective at face value, then perhaps the best we can do here as cognitive scientists is to catalogue some further cases of inspired genius and then admire them in perpetual awe.

## The Prepared-Mind Perspective

Nonetheless, despite the preceding mixed prognosis, some adventurous scholars have forged ahead with attempts to explore the sources of insight in both acknowledged geniuses and ordinary people. As a result, a third point of view, which we call the *prepared-mind perspective* (Posner, 1973), has come into focus. According to it, true insight may indeed occur on some occasions, just as the Wizard Merlin perspective claims. However, also somewhat attuned with business as usual, the prepared-mind perspective does not necessarily attribute cases of insight to enigmatic superhuman mental powers. Rather, on the assumption that insight is a researchable cognitive phenomenon, the latter viewpoint strives toward determining how insight may emerge from a combination of information-processing phases whose joint interactions enable subconscious quantum leaps during the generation of new mental products.



An early example of this endeavor appeared in *The Art of Thought* by Graham Wallas (1926). Working from introspective reports of some prominent creative individuals, Wallas outlined four major phases of information processing that may mediate innovative problem solving and creativity. These phases consist of a synergistic combination of (1) *mental preparation*, (2) *incubation*, (3) *illumination*, and (4) *verification*. At the start of this sequence, the initial preparation phase supposedly entails confronting an important problematic situation, conceptualizing the problem's core aspects, and making exerted tentative unsuccessful attempts to reach a satisfactory resolution. Next, the incubation phase consists of putting the problem aside and thinking instead about other matters for an extended period of time. Then, at some point during incubation, there is an abrupt shift to the illumination phase, wherein a penetrating flash of insight about an appropriate satisfying resolution to the original problematic situation occurs unexpectedly. Given the attained insight, the final verification phase culminates with working out the details of the resolution or determining that it applies successfully.

A compelling, ubiquitously cited illustration of these information-processing phases may be found in the memoirs of the great French mathematician, Henri Poincaré, who offered the following anecdote about his own creative processes (Poincaré, 1913; cited in Mayer, 1992, p. 49):

For fifteen days I strove to prove that there could not be any functions like those I have since called Fuchsian functions. I was then very ignorant; every day I seated myself at my work table, stayed an hour or two, tried a great number of combinations and reached no results. One evening, contrary to my custom, I drank black coffee and could not sleep. Ideas rose in crowds; I felt them collide until pairs interlocked, so to speak, making a stable combination. By the next morning I had established the existence of a class of Fuchsian functions, those which come from the hypergeometric series; I had only to write out the results which took but a few hours.

> Just at this time I left Caen, where I was then living, to go on a geologic excursion under the auspices of the school of mines. The changes of travel made me forget my mathematical work. Having reached Countances, we entered an omnibus to go some place or other. At the moment when I put my foot on the step the idea came to me, without anything in my former thoughts seeming to have paved the way for it, that the transformations I had used to define the Fuchsian functions were identical with those of non-Euclidean geometry.... On my return to Caen, for "conscience" sake I verified the result at my leisure.

Moreover, this sort of experience does not appear unique to Poincaré. Numerous compendiums of introspective reports by other innovative mathematicians, scientists, artists, and musicians who have achieved creative insights all subjectively document the occurrence of intense mental preparation, subsequent long-term subconscious incubation, and abrupt unanticipated illumination as crucial precursors to desirable new cognitive products (e.g., Ghiselin, 1952; Koestler, 1964). Personal self-help experts (e.g., Anderson, 1980; Hayes, 1989) have likewise suggested that these precursors may contribute, albeit in less spectacular fashion, to the lives of ordinary people. Consequently, Wallas's (1926) componential analysis of the creative process has been widely disseminated as the received wisdom in popular cognitive psychology textbooks (e.g., Anderson, 1990; Glass & Holyoak, 1986; Halpern, 1989; Hayes, 1978; Lindsay & Norman, 1977; Mayer, 1992; Posner, 1973; Solso, 1988).

Although obviously incomplete, this wisdom may have some further significance as well for us. In particular, Wallas's (1926) analysis points toward at least two obvious places where we might find some wellsprings of insight. One of these is the initial preparation phase, and the other is the intermediate incubation phase, which together supposedly culminate with illumination. If we could determine exactly what mental processes transpire during them, before an insightful outcome emerges, then perhaps we would discover much, if not all, of what there is to know about the nature of insight.

## PAST STUDIES OF THE PREPARATION PHASE

Unfortunately, when we pursue this train of thought further and examine past studies of the initial preparation phase in problem



solving, the results prove rather disappointing. What we mainly find is why many people *fail* to experience immediate flashes of insight on a regular basis. Normal problem-solving attempts seem to suffer from at least two initial roadblocks. First, people often neglect to exploit information that they have previously stored in memory and that is at least indirectly relevant to solving a given problem. The tendency toward such neglect is particularly evident among novices for whom the problem comes from a domain with which they are not already familiar. A second major roadblock is that when people do apply previously memorized information in an attempt to solve new problems, they often use the information inappropriately. In effect, this then makes the problem even more difficult than it might otherwise have been. Thorough accounts of both these roadblocks to creativity appear in many cognitive psychology textbooks (e.g., Anderson, 1990; Glass & Holyoak, 1986; Halpern, 1989; Hayes, 1978; Lindsay & Norman, 1977; Mayer, 1992; Posner, 1973; Solso, 1988).

### Failure to Apply Relevant Prior Information

A well-known demonstration of the first roadblock—failure to apply relevant prior information—has been provided by Gick and Holyoak (1980). In their study, test subjects were asked to give insightful solutions for puzzles such as Duncker's (1945) radiation problem. This problem requires devising a method through which a tumor deep inside a patient's body can be destroyed by a source of radiation without causing any serious damage to surrounding healthy tissue. The most appropriate solution, whose discovery does not typically come easily, involves arranging the radiation such that small amounts of it are directed simultaneously at the tumor along each of many different pathways, summating at the tumor's central site but not creating excessive exposure to the healthy tissue that each pathway traverses.

Before assessing the extent to which their subjects would discover this solution, Gick and Holyoak had some of the subjects read short stories whose content described other situations that were structurally analogous to the forthcoming problem and solution. For example, one of these stories told of a fictitious militaristic attack-and-dispersion situation (Gick & Holyoak, 1980, p. 311):

A fortress was located in the center of a country. Many roads radiated out from the fortress. A general wanted to capture the fortress with his army. He wanted to prevent mines on the roads from destroying his army and neighboring villages. As a result, the entire army could not attack the fortress along one road. However, the entire army was needed to capture the fortress. So an attack by one small group would not succeed. The general therefore divided his army into several small groups. He positioned the small groups at the heads of different roads. The small groups simultaneously converged on the fortress. In this way, the army captured the fortress.

Clearly, this attack-and-dispersion story is relevant to solving Duncker's radiation problem; both of them concern situations in which a central object of attack (i.e., fortress or tumor) can and should be approached by dividing a source of power (i.e., troops or radiation) and directing it along multiple pathways. Under a variety of conditions, however, Gick and Holyoak (1980, 1983) found that presenting such stories to subjects beforehand did not substantially enhance their later success at problem solving compared to control subjects who received no stories. Other investigators have, on multiple occasions, obtained a similar disappointing lack of analogical transfer in the solution of insight problems, even when one might have expected the relevance of certain prior information to seem blatantly obvious (e.g., Perfetto, Bransford, & Franks, 1983; Weisberg, Dicamillo, & Phillips, 1978). The implication, then, is that people may lack easy automatic access to such information during their solution attempts, thereby impeding progress toward insight.

## Inappropriate Use of Stored Information

Progress toward insight may also be impeded by the second roadblock, whereby seemingly relevant stored information is accessed but used inappropriately during problem-solving attempts. In this regard, the phenomena of *functional fixedness* and *Einstellung* (problem-solving set) noted by the classical Gestalt psychologists are prime cases (e.g., Duncker, 1945; Luchins, 1942). For example, a good illustration of incipient functional fixedness appears in figure 3.3, which shows the so-called two-string problem that



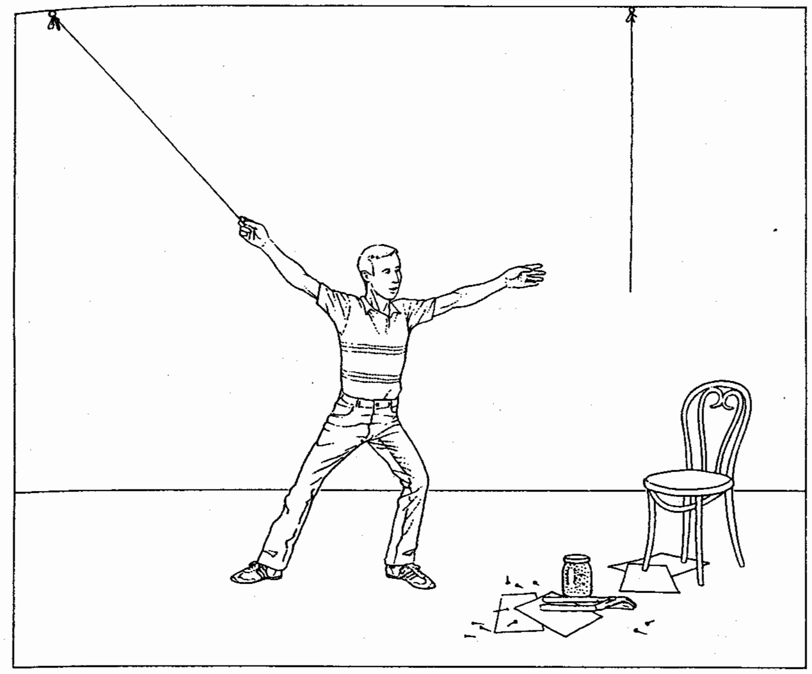


**Figure 3.3**
Maier's two-string problem. The insightful solution involves tying the pair of pliers on the floor to one of the strings and then swinging the string like a pendulum so it approaches the other string and both may be grasped simultaneously and tied together. (Reprinted with permission from Anderson, 1990, p. 247.)

Maier (1931) presented to subjects for solving. Here the subjects must tie together the ends of two strings suspended vertically from a ceiling, even though the strings are widely separated and cannot be grasped simultaneously at the outset. Rather, an insightful solution requires using some other available object (e.g., a jar, pliers, or chair on the floor) as an aid.

Among the solutions that Maier (1931) envisioned as being especially insightful, one involved a pair of pliers. This solution required four steps: (1) attaching the pliers to the end of one string, thus treating them as a weight; (2) swinging the string with the attached pliers back and forth like a pendulum, bringing it closer to the other stationary string; (3) catching the swinging string while holding the stationary one; and (4) tying the two strings together. Like the solution to Duncker's radiation problem, however, this solution to the two-string problem did not come easily for subjects. Instead, it seems that they may have been biased toward viewing the pliers as a type of tool for grasping and pinching objects, not as a weight for making a swinging pendulum. If so, then their prior stored knowledge about pliers could actually have hindered them, and they might have been better off if they had never heard of pliers before (Glucksberg & Danks, 1968; Glucksberg & Weisberg, 1966)!

### Countervailing Benefits from Prior Knowledge

Of course, specific prior knowledge does not always hinder subsequent problem-solving activity. As mentioned previously, people who are experts at dealing with particular domains may benefit from their prior knowledge in solving problems there. For example, a prototypical case of benefits due to expertise has been reported by Chase and Simon (1973; also see de Groot, 1965), who found that chess masters are superior to chess novices at remembering meaningful arrangements of pieces on a chessboard. The structure of the masters' stored knowledge about chess positions presumably facilitates their ability to select good moves.

Such benefits may likewise accrue to novice problem solvers under at least some circumstances. In particular, during follow-ups to the work of Gick and Holyoak (1980, 1983) on analogical problem solving, some other investigators have found that if one problem is preceded by prior relevant information framed as another analogous problem, rather than as a mere set of declarative facts, then people may transfer the prior information much more readily to the subsequent problem (Adams, Kasserman, Yearwood, Perfetto, Bransford & Franks, 1988; Lockhart, Lamon & Gick, 1988; Needham & Begg, 1991). This suggests that insight might ultimately stem from special types of memory organization used in storing information from problematic contexts. As will become more apparent later, our own theoretical ideas and empirical data reinforce this latter prospect.

Some additional evidence that foreshadows our ideas comes from studies in which experimenters have interrupted subjects



during problem solving. Their results suggest two related conclusions. First, people who spend more time on their initial solution attempts before an interruption are more likely to achieve ultimate successful solutions when they later return to the problems (e.g., Silveira, 1971; cited in Posner, 1973, pp. 172–173). Second, under at least some circumstances, people exhibit greater recall of problems on which they have been interrupted than of problems on which they have reached a successful solution (Baddeley, 1963, 1976; Seifert & Patalano, 1991; Zeigarnik, 1927).

Yet the ultimate significance of such results for understanding the nature of insight remains to be determined. On the one hand, the results may simply reflect the fact that stored information tends to stay in a more activated state when initially processed for a longer time. If so, then this would suggest nothing unique about insight per se, given what is known already about human memory in general and its dependence on the duration of exposures to new information (Baddeley, 1976). On the other hand, enhanced recall as a function of problem-solving interruption, and increased solution probability as a function of problem-exposure duration, could also stem from special memory structures and processes dedicated to attaining insightful solutions after initial failures (Hammond & Seifert, 1993; Meyer, Yaniv & Davidson, 1988; Patalano, Seifert & Hammond, 1993; Yaniv & Meyer, 1987; Yaniv, Meyer & Davidson, 1993). Further research on the preparation phase of problem solving is therefore needed to test and discriminate among these various possibilities.

## PAST STUDIES OF THE INCUBATION PHASE

Some open questions and potential answers about the nature of insight have also emerged from past studies of Wallas's (1926) proposed incubation phase in problem solving. In evaluating them, it is important to recognize that research on incubation is inherently difficult. To conduct such research properly, an experimenter must first engage test subjects in solving a hard problem, have them initially fail but maintain their interest in the problem, then control what happens during a subsequent incubation phase, and be present later if, by chance, illumination shines forth, so that unobservable mental states surrounding eventual insights are accurately and discriminatingly recorded. Together, these requirements constitute a large order that has seldom, if ever, been completely filled. Nevertheless, a modicum of progress has been made toward delineating and testing alternative hypotheses about mental processes that may occur during incubation and eventuate in insight (e.g., Cook, 1937; Dominowski & Jenrick, 1972; Ericksen, 1942; Fulgosi & Guilford, 1968; Murray & Denny, 1969; Olton & Johnson, 1976; Patrick, 1986; C. Patrick, 1935, 1937; Silveira, 1971; Smith & Blankenship, 1989; Weisberg & Suls, 1973).

### Hypotheses about Incubation Effects

Among the hypotheses considered most extensively are four possibilities (for a review, see Anderson, 1990; Glass & Holyoak, 1986; Posner, 1973). The first, and least interesting, of these is the *conscious-work hypothesis*. As this hypothesis would have it, the incubation phase simply provides time during which intermittent covert conscious work on a problem takes place after an initial preparation phase, thus setting the stage for rapid observable progress toward solution when the problem is later overtly reconfronted. A second mundane possibility is the *fatigue-dissipation hypothesis*. According to it, the incubation phase allows people to recover from debilitating mental fatigue caused by the intensity of the initial preparation phase, thereby increasing the likelihood of subsequent successful solution when the problem is later reconfronted in a refreshed state. Related to the fatigue hypothesis, but more interesting from a cognitive standpoint, is the *selective-forgetting hypothesis*. This third possibility assumes that after the initial preparation phase, the incubation phase allows stymied problem solvers to forget inappropriate solution strategies that distracted them initially but that leave relatively weak residual memory traces. Fourth, and most mysteriously, there is the *subconscious random-recombination hypothesis*, according to which an incubation phase after intense preparation allows various bits of relevant information stored in long-term memory to be recombined subconsciously with one another through a random process that ultimately yields a fortuitous insightful synthesis of ideas. The recombination process might, for example, involve a gradual spread of activation among the elements of associative memory networks (Bowers et al., 1990; Yaniv & Meyer, 1987).



In assessing these various possibilities, a mix of the subconscious random-recombination and conscious-work hypotheses seems most favored by the introspective reports of some creative individuals. For example, Poincaré, the French mathematician, provided the following conjectures about what happens during incubation (Poincaré, 1913, cited in Anderson, 1975, p. 288; also see Ghiselin, 1952, p. 41):

> Permit me a rough comparison. Figure the future elements of our combinations as something like the hooked atoms of Epicurus. During the complete repose of the mind, these atoms are motionless, they are, so to speak, hooked to the wall; so this complete rest may be indefinitely prolonged without the atoms meeting, and consequently without any combination between them. On the other hand, during a period of apparent rest and unconscious work, certain of them are detached from the wall and put in motion. They flash in every direction through the space ... where they are enclosed, as would be, for example, a swarm of gnats or, if you prefer a more learned comparison, the molecules of gas in the kinematic theory of gases. Then their mutual impacts may produce new combinations.

### Laboratory Studies of Mental Incubation

In contrast, systematic laboratory studies of incubation in problem solving cast some doubt on the validity of such introspections. When experimenters have subjected the mental processes associated with incubation to close controlled scrutiny, two different types of conclusion have emerged instead; either the beneficial effects of incubation on solution activities have been difficult to detect and limited to subsets of subjects (e.g., Cook, 1937; Ericksen, 1942; Murray & Denny; 1969; Dreistadt, 1969; Olton, 1979; Olton & Johnson, 1976) or they have appeared to stem primarily from fatigue dissipation and selective forgetting rather than from a more exotic process of subconscious random recombination of ideas (e.g., Silveira, 1971; Smith & Blankenship, 1989).

An oft-cited illustration of the latter outcome may be found in the study by Silveira (1971). She used the so-called four-chain problem, which goes as follows (Posner, 1973, p. 172):

A man had four chains, each three links long. He wanted to join the four chains into a single closed chain. Having a link opened cost two cents and having a link closed cost three cents. The man had his chains joined into a closed chain for fifteen cents. How did he do it?

After presenting this problem to her test subjects, Silveira (1971) let a control group of them work on it continuously for a half hour, and she observed what proportion of this group solved the problem. Also, the study included four other experimental groups, each of which was interrupted at some point during the initial problem-solving attempt and then brought back subsequently to resume it following an intervening incubation phase. The experimental groups differed from one another and the control group in terms of how much time they spent working on the problem initially (either brief or long preparation) and in terms of how much time they had to incubate before resumption (either a half hour or 4 hours).

Silveira's results showed that the probability of eventually solving the four-chain problem was highest (.85) for the experimental group who had both long preparation and long incubation, intermediate (.64) for the group who had long preparation but short incubation, and less for the other groups. In particular, only about half of the control group who had no incubation phase successfully solved the problem. However, the combination of long preparation and incubation phases did not appear to yield new insights of the sort implied by the subconscious random-recombination hypothesis and Poincaré's speculations about it. Instead, the subjects who prepared and incubated the most in Silveira's (1971) study may have achieved a relatively high solution rate through a different route. They tended to be more focused and persistent in resuming their solution attempts with a promising direction of thought that they had already evolved during the initial preparation phase. This is most consistent with selective forgetting and fatigue dissipation.

Various conclusions might be reached on the basis of this and other past studies of the incubation phase: Perhaps new insights from incubation seldom, if ever, occur. Perhaps mental processes during incubation do not involve residual spreading activation, subconscious random recombination, and other exotic activity



that could yield new insights. Alternatively, past studies may not have been conducted well enough to reveal such processes; maybe the problems were not sufficiently motivating, the amounts of preparation and incubation were too little, and the subjects were too normal to exhibit true insightful incubation effects.

## EXPANSION OF THE PREPARED-MIND PERSPECTIVE

Whatever the merits of the latter conclusions, we believe that the prepared-mind perspective has much to recommend it but that its focus should be expanded to highlight other possible sources of insight and other possible mechanisms of facilitative mental preparation and incubation. In particular, the hypotheses outlined previously regarding incubation effects seem too narrow. They focus exclusively on internal processes that are assumed to occur inside the problem solver during incubation, without any further outside stimulation from the physical environment after initial preparation. Under the selective-forgetting and subconscious random-recombination hypotheses, for example, incubation would enable progress toward successful solution of a prior problem even if the problem solver were placed in a sensory-deprivation chamber. The potential key role that external events could play as part of the incubation phase is completely ignored by these hypotheses. Nevertheless, it seems plausible to expect that insight would occur more naturally through ongoing incidental interaction with a rich surrounding physical environment.

As Louis Pasteur put it (Posner, 1973, p. 148), "Chance favors the prepared mind." What he presumably meant by this is not that random self-generated recombinations of ideas occur most often to people whose minds are prepared, but rather that prepared minds can and do take advantage of fortuitous encounters with relevant external objects and events. The virtues of mental preparation and opportunistic processing of lucky new experiences have likewise begun to be echoed by cognitive scientists and the artificial intelligencia (e.g., Hammond & Seifert, 1993; Hammond, Seifert & Gray, 1991; Hayes-Roth & Hayes-Roth, 1979; Laird, Rosenbloom & Newell, 1987; Patalano, Seifert & Hammond, 1993; Schank, 1982; VanLehn, 1988).

## Relevant Notions from Cognitive Science

Among the notions advocated recently in cognitive science, several are especially relevant to us here. VanLehn (1988) has suggested that significant learning is most likely to occur and to yield lasting benefits at points where an individual reaches an impasse in information processing and then receives new information about how to overcome the impasse. VanLehn's (1988) term for this occurrence is *impasse-driven learning.* He found that it may happen, for example, during instruction on solving arithmetic problems. We assume that impasse-driven learning can contribute to many other types of problem solving as well.

To account for the occurrence of impasse-driven learning not just at the time of an initial impasse but also at future times, Patalano, Seifert, and Hammond (1993) suggested that people engage in *predictive encoding*, a memory strategy whereby information about an impasse is represented and stored in terms of characteristics (e.g., physical and conceptual features) that helpful future stimulus cues may have. On the basis of predictive encoding, these cues, when encountered in the future, can then be related directly back to the impasse and used to resolve it (Hammond, Converse, Marks & Seifert, 1993). This retroactive facilitative access can also be promoted through *failure indices*, which mark information in memory associated with the original occurrence of an impasse (Hammond, Seifert & Gray, 1991; Meyer, Yaniv & Davidson, 1988; Schank, 1982; Yaniv, Meyer & Davidson, 1993).

## The Opportunistic-Assimilation Hypothesis

With the preceding notions in mind, we want to promote an additional explicit hypothesis about how insight may stem from the mental preparation and incubation phases of problem solving and other potentially creative activities (Hammond, Seifert & Gray, 1991; Meyer, Yaniv & Davidson, 1988; Patalano, Seifert & Hammond, 1993; Yaniv, Meyer & Davidson, 1993). Our rubric for this is the *opportunistic-assimilation hypothesis.*

### Importance of Impasses

According to the opportunistic-assimilation hypothesis, initial information-processing encounters with problematic situations



that end in an impasse (e.g., failure to solve a problem on the first try) leave failure indices in long-term memory. We assume that these special memory traces (the details of which will be described more fully later) explicitly mark the fact that an impasse has occurred. They may then serve as signposts that guide subsequent retrieval processes back to stored aspects of the problematic situation (Schank, 1982).

Under our opportunistic-assimilation hypothesis, an impasse reached during the initial preparation phase of problem solving can set the future stage in other complementary ways. For example, proceeding until impasse helps ensure that all originally available information gets considered and used in the best way possible at the time. This maximizes the degree to which the tentative partial representation of a problem will have an appropriate stable form, like a nearly completed jigsaw puzzle, ready to receive other crucial missing pieces or to be rearranged in an efficient systematic manner after a subsequent incubation phase.

### Role of Incubation

Next, regarding the incubation phase, we further assume that a person who has experienced a problem and reached an impasse puts the problem aside and goes about his or her other business. During this subsequent period, numerous encounters with various environmental stimuli may occur and be processed, but no further conscious or subconscious work on the original problem would take place. Nevertheless, according to our opportunistic-assimilation hypothesis, the course of daily events may eventually lead to a fortuitous encounter with an external object or event that is especially relevant to solving the original problem. If so, then as this stimulus and the cues therein are processed through normal ongoing perception and comprehension, they will contact the failure indices that commemorate the original problem.

Under our hypothesis, contact with the "red flags" provided by these special memory traces triggers a process through which the new stimulus is used in an attempt to resolve the old problem. The resulting attempt may involve simply assimilating the new stimulus into the prior memory representation of the problem, like adding a missing piece to a jigsaw puzzle while keeping the previously placed pieces in their former positions. Alternatively, both some assimilation and restructuring might occur, as when the positions of some puzzle pieces are changed to accommodate a new one. Either way, we propose that the end result is a primary source of the insight experience.

**Past Precedents Regarding Opportunistic Assimilation**

Of course, our proposal and its expansion of the prepared-mind perspective is not entirely new. As mentioned earlier, the possibility that insight may stem from chance encounters with external objects or events, which then interact with previously prepared mental structures, was explicitly articulated much earlier by Pasteur (cited in Posner, 1973, p. 148). This potential source of insight has been acknowledged in a few cognitive psychology textbooks (e.g., Anderson, 1975; Posner, 1973). For the most part, however, textbook authors have either ignored the opportunistic-assimilation hypothesis entirely or given it rather short shrift (e.g., see Glass & Holyoak, 1986; Solso, 1988).

## Virtues of Opportunistic Assimilation

Despite its lack of past prominence, the opportunistic-assimilation hypothesis has numerous appealing virtues. For example, it lets us neatly synthesize some of the main themes that characterize the prepared-mind and business-as-usual perspectives on the nature of insight. Furthermore, even the Wizard Merlin perspective may join this desirable synthesis.

**Synthesis of Alternative Perspectives**

The impasse-driven storage of failure indices at the end of initial preparation, followed by later opportunistic assimilation through ongoing comprehension processes, are consistent with some key claims that advocates of business as usual have made (e.g., Weisberg & Alba, 1981a, 1981b). In particular, it is known already that impasses can drive learning under a variety of circumstances (VanLehn, 1988), failure indices can mediate retroactive access to information about prior failures (Hammond, Seifert & Gray, 1991; Meyer, Yaniv & Davidson, 1988; Schank, 1982; Yaniv, Meyer & Davidson, 1993), and beneficial opportunism can occur when relevant new stimulus situations are encountered (Hayes-Roth & Hayes-Roth, 1979; Meyer, Yaniv & Davidson, 1988; Patalano, Seifert & Hammond, 1993; Yaniv, Meyer & Davidson, 1993). The application of these notions to the nature of insight then, in essence, retains a large measure of business as usual.

Yet at the same time, this application does not entirely disavow the mental powers that the Wizard Merlin perspective attributes to great masters of insight. Under our present hypothesis, truly masterful insights can come from an interplay among predictive encoding, storage of failure indices, opportunistic assimilation, and the sagacity of the initial memory representation that an intellectual magician forms for a problematic situation (see Lockhart et al., 1988). Although both ordinary people and these magicians may experience the joys of insight, the frequency and depth of the joy might differ, depending on the richness and profundity of the prior preparation phase. Thus, we may have some more helpful clues about where to look—namely, at the details of the initial problem representation—to better understand how intellectual magicians achieve their feats.



**Explanation of Phenomenological Characteristics**

A second related virtue of the opportunistic-assimilation hypothesis and our expansion of the prepared-mind perspective is that they easily explain why insight seems to have so many intriguing phenomenological characteristics. As outlined earlier in this chapter, among these characteristics are nonanalyticity, subconsciousness, suddenness, spontaneity, unexpectedness, and satisfaction. Each of these mystical properties arises quite naturally in our view, from more "normal" processes.

To be specific, suppose that a problem solver has stored a stable, partial mental representation of an unsolved problem, and he or she later accidently encounters a crucial missing piece of information that completes it. Then this would cause a sudden change in the prospects for solution. The change may seem spontaneous because the problem solver was not expecting or intending it to happen at the particular moment, and the use of the new information will not necessarily be conscious, because normal perception and comprehension processes work automatically (Lachman et al., 1979), leaving the problem solver unable to explain the resulting solution path. The delay of the solution until the present encounter encourages the feeling that it is intuitive and that it could not have been deduced from prior preparation alone. Also, the satisfying nature of the insight experience is explained by the triumphant filling of a gap in the initial mental representation of the problem. In fact, the sense of elation that accompanies the ultimate "Aha!" experience could serve an important function; it might facilitate the opportunistic assimilation process by increasing physiological arousal and promoting stronger memory consolidation (Baddeley, 1976).

**Support from Laboratory Research**

The preceding account of why insight has certain phenomenological characteristics gains additional support from the results of previous laboratory research on problem solving. In his influential studies with the two-string problem (see figure 3.3), Maier (1931) included a condition under which he let subjects spend several minutes trying to solve the problem of their own accord. Many failed during this initial phase. Next, some of Maier's subjects received a subtle hint about how the problem could and should be solved. The hint was given by an experimenter who casually brushed against one of the hanging strings, setting it briefly and unobtrusively into motion. Subsequently, within a short period of time, a large fraction of the stymied subjects successfully achieved the appropriate pendulum solution, tying the available pair of pliers to one of the strings and swinging it over near the other string, where both of them could then be grasped simultaneously and tied together. However, many of the subjects who achieved success had no idea about how they arrived at the appropriate solution; they claimed to be completely unaware of the hint. This is exactly what we would expect if opportunistic assimilation of relevant new information occurs through rapid, automatic, subconscious processes of normal perception and comprehension.

That opportunistic assimilation is mediated by prior predictive encoding and storage of failure indices, which result from an initial encounter with a problem, also gains support from some previous laboratory research. In one study, for example, Lockhart and colleagues (1988) gave subjects descriptions of problematic situations that had to be explained. These descriptions consisted of scenarios such as: "A man who lived in a small town married 20 women of the same town. All are still living and he never



divorced a single one of them. Yet he broke no law. How could this be?" Before trying to provide the explanation, the subjects received other relevant information expressed in either a simple declarative or temporarily puzzling form. The prior information consisted of statements such as, "It made the clergyman happy to marry several people each week" (declarative form) or "The man married several people each week because it made him happy" (puzzling form), which was then followed by the word *clergyman*.

Lockhart and colleagues' data (1988) showed that subsequent explanations of the problematic descriptions were markedly facilitated by receipt of prior information in a puzzling form, whereas prior information in a simple declarative form had much less benefit. This is exactly what we would expect if the puzzling form of the prior information caused predictive encoding to occur and failure indices to be stored, thus promoting beneficial access when the subsequent problematic descriptions were presented. In essence, the predictive encoding and failure indices proposed here enable what others have called *transfer-appropriate processing* (Adams et al., 1988; Needham & Begg, 1991; Weisberg & Suls, 1973).

**Consistency with Anecdotal Cases**

The opportunistic-assimilation hypothesis is likewise consistent with a broad sample of anecdotal cases involving alleged occurrences of insight, ranging from the mundane to the spectacular. As mentioned previously, two such cases are those involving the man who fell to earth and Newton's apple. In each of them, insight occurred through an encounter with an unexpected but relevant new external event after an initial problem-solving impasse had been reached. First, there was the stimulus provided by the desert wanderer's accidental dropping of his handkerchief, which triggered the insight that the man who fell to earth had met his demise through a broken parachute. Second, there was the stimulus provided by the falling apple in the English countryside, which inspired Newton to associate the earth's pull with the motions of heavenly bodies, yielding his universal law of gravitation.

Continuing along such lines, we should mention some other noteworthy cases. Interestingly, one of the first main observations that led classical Gestalt psychologists to focus on insight in problem solving involved an apparent instance of opportunistic assimilation (Kaplan & Simon, 1990). The case concerns Sultan, a chimpanzee observed extensively by Köhler (1956). During his studies of Sultan, Köhler placed the chimp in a cage, outside of which were some bananas on the floor. Sultan would have liked to eat one of them immediately, but they were too far from the cage for the chimp to reach them directly. Inside the cage, there were two separate sticks, which Sultan had previously learned to use for manipulating objects. However, neither of the sticks was long enough to reach one of the bananas. In other words, Sultan had a problem. Therefore, he stopped attending to the bananas and went about his other business for the moment, after which the following events occurred, as recounted by Köhler (1956, p. 127; cited in Kaplan & Simon, 1990):

> Sultan first of all squats indifferently on the box, which has been left standing a little back from the railings; then he gets up, picks up the two sticks, sits down again on the box and plays carelessly with them. While doing this, it happens that he finds himself holding one stick in either hand in such a way that they lie in a straight line; he pushes the thinner one a little way into the opening of the thicker, jumps up and is already on the run toward the railings, to which he has up till now half turned his back, and begins to draw a banana toward him with the double stick.

At the risk of overanthropomorphizing Sultan's behavior or underestimating his imaginative powers, we would suggest that this anecdote illustrates another prime instance of opportunistic assimilation after an initial problematic impasse. What Sultan seems to have done here is enter an incubation phase that ended with him noticing the chance conjunction of the two sticks, after which he related their contiguity back to his prior problem with reaching a banana, made the necessary additional connection, and proceeded insightfully to use the conjoined sticks for solving his problem. Given our opportunistic-assimilation hypothesis and expansion of the prepared-mind perspective, we would therefore agree with Köhler (1956) that Sultan's behavior indeed manifested significant insight. We would also emphasize that although the insight was clearly real, it did not require the powers of an intellectual magician, consistent with some of the theories of advocates of business as usual (e.g., Weisberg & Alba, 1981a).



In the same spirit, albeit at a more profound level, numerous significant cases of insight on the basis of predictive encoding and opportunistic assimilation can be extracted from the anecdotal reports of famous scientists, mathematicians, artists, and writers (Ghiselin, 1952; Koestler, 1964). Such reports go back at least as far as the time of Archimedes, whose laws of hydrodynamics were reputedly inspired through insights reached while he was taking a casual bath and watching the surrounding water rise, which culminated in his exclamation, "Eureka!" Complementing this example, other more contemporary instances include two major biological innovations: Alexander Fleming's discovery of penicillin, which stemmed from his accidentally noticing an absence of bacterial growth on the bottom of a dish; and the discovery of DNA's structure by James Watson and Francis Crick, who are rumored to have first gained insight about the double helix while sliding down the railing of a spiral staircase and daydreaming of the Nobel prize. (The reply to Watson's asking Crick about exactly where their insight had come from was purportedly, "Elementary, my dear Watson, elementary"; cf. Conan Doyle, 1981).

**Relation to Feynman and the Wizard Merlin Perspective**

Indeed, even our prototypical intellectual magician, Richard Feynman, whose exploits were chronicled earlier, appears to have gotten some of his best insights through the route of predictive encoding, failure indices, fortuitous stimulus encounters, and opportunisitic assimilation. One particular episode recounted by him stands out in this regard (Gleick, 1992). Feynman's problem here was to formulate a successful theory of beta decay (transformation of neutrons into protons and electrons) and other elementary particle interactions governed by the fundamental weak force of nature. After filling himself for months with preliminary relevant information, and after striving mightily without success, he took a summer vacation to Brazil, where he went regularly to play the bongos and sit on Ipanema Beach. On returning home to the California Institute of Technology, he began interacting again with colleagues about the weak force, which led to the following Feynman recount (quoted in Crease & Mann, 1986, pp. 213–214):

Finally they get all this stuff into me, and they say, "The situation is so mixed up that even some of the things they've established for years are being questioned—such as the beta decay of the neutron is *S* and *T* [a specific type of particle interaction]. Murray [Gell-Mann] says it might even be *V* and *A* [another specific type of particle interaction], it's so messed up." I jump up from the stool and say, "Then I understand EVVVVVERY-THING!" They thought I was joking. But the thing I had trouble with at the Rochester meeting [a previous conference]—the neutron and proton disintegration: Everything fit *but* that, and if it was *V* and *A* instead of *S* and *T*, that would fit too. Therefore, I had the whole theory! . . . I went on and checked some other things, which fit, and new things fit, new things fit and I was very excited. . . . I had this new equation for beta decay. . . . It was the first time, and the only time, in my career that I knew a law of nature that nobody else knew.

Gratifyingly, this quote bodes well for our prospects of developing a general, scientifically testable, cognitive theory of insight that applies to a broad range of individuals. Contrary to previous intimations about Feynman's source of insights (Gleick, 1992, pp. 311–329), it seems that he did not experience insight solely from writing down a problem, closing his eyes, thinking hard, pressing his forehead repeatedly, and then writing down the solution. Instead, we find here that even reputed intellectual magicians, whose spectacular mental feats constitute the focus of the Wizard Merlin perspective on insight, are, by their own admission, major benefactors of predictive encoding and opportunistic assimilation, as our expansion of the prepared-mind perspective would have it. If we take Feynman at his word, then of all his innovations, the best one stemmed from a fortuitious encounter with a relevant but unexpected new event in the environment; someone casually mentioned to him that the *V-A* rather than *S-T* particle interaction might be primary, and he proceeded from there on the basis of extensive prior preparation.

## STUDIES OF IMPASSES AND OPPORTUNISTIC ASSIMILATION

Of course, one could ask for more support from studies with controlled laboratory methods rather than just anecdotal observation. A worthwhile focus of such studies would appear to be impasse-driven predictive encoding and opportunistic assimilation, given that individuals who have diverse mental abilities, ranging from chimpanzees (e.g., Sultan) through normal college students to intellectual magicians (e.g., Feynman), all apparently reach insight at least partly through these processes. In this section, we therefore describe briefly some results of two representative experiments conducted in our laboratories to investigate these processes further. Our experiments test several specific related predictions that follow from the opportunistic-assimilation hypothesis and the prepared-mind perspective.

For present purposes, we will focus on two such predictions. The first is that ultimate successful solution of an initially unsolved problem will be much more likely if stymied problem solvers are exposed surreptitiously to relevant new information during a subsequent incubation phase. A second prediction tested here is that problem solvers will be much more likely to recall their encounter with a prior problem if they have reached an initial impasse on it than if their solution attempt is interrupted without an impasse being reached.



### Experiment 1: Answering Problematic Factual Questions

Our first experiment was designed specifically to test the prediction that exposing problem solvers to relevant new information after an initial failed solution attempt will best promote ultimate successful solutions (for more details, see Meyer, Yaniv & Davidson, 1988; Yaniv, 1988; Yaniv, Meyer & Davidson, 1993).

#### Method

In pursuit of this objective, we adopted and extended an experimental method developed previously by Yaniv and Meyer (1987). The method involved three phases of testing, which roughly paralleled three of the problem-solving phases that Wallas (1926) has proposed.

During experiment 1's first phase, test subjects (undergraduate college students) were presented with general-information questions such as, "What is a nautical instrument used in measuring angular distances, especially the altitude of the sun, moon, and stars at sea?" These questions came from a set whose answers were presumably known but used infrequently by most of the subjects, as determined through a prior pilot study.

For each question presented in phase 1, the subjects tried to provide the correct answer. They were allowed as much time as they desired to do so. Sometimes they actually succeeded. If so, then we had them rate their confidence that their answer was correct, using a five-point scale. On other occasions (approximately 33 percent of the time), however, the subjects failed in their attempts to provide answers, and they gave up because the presented questions were difficult enough to pose a problematic memory-retrieval situation. When the subjects abandoned their attempts to answer a question, we asked them to rate their "feeling of knowing" about the correct answer before proceeding to the next question.

Following presentation of the general-information questions and solicitation of the correct answers, there was a second phase, during which the subjects were shown a sequence of visual letter strings on a display screen. The letter strings included a variety of words and nonwords (e.g., *spending, dascribe, sextant, trinsfer, asteroid, umbrella,* and so forth). For each string of letters displayed, the subject had to decide whether it was an English word or nonword, indicating the decision quickly and accurately by pressing either a "yes" or "no" button. Thus, the second phase consisted of a *lexical-decision task* (Meyer & Schvaneveldt, 1971).

The subjects were not told that the lexical-decision task of phase 2 had any specific relationship to the prior problematic question-answering task of phase 1; rather, phase 2 was, in essence, a subsequent incubation phase. Nonetheless, among the stimuli displayed, there were *target words* that would have been correct answers to some of the prior general-information questions on which the subjects initially failed. The lexical-decision task therefore provided an opportunity for incidental exposures and assimilation of the solutions to some previous problematic impasses. Also included among the stimuli were *control words* that provided additional distraction and served subsequent informative comparison purposes. For both the control and target words, as well as the nonwords, we measured the subjects' reaction times and accuracy in making their lexical decisions.

After phases 1 and 2 of the experiment, which were conducted in the same test session, the subjects took the rest of the day off. This allowed an additional period of incubation. Then, on the next day, they returned again for more testing in a third phase.

Phase 3 involved more general-information questions, for each of which the subjects tried to provide the correct answer, as in the first phase. Among the phase 3 questions were some that had been presented during phase 1 and other questions not seen previously in the experiment (e.g., "What do you call one of the thousands of small planets between Mars and Jupiter with diameters from a fraction of a mile to nearly 500 miles?"). The old and new questions had another important property. For some of them, both old and new, the target words that constituted their answers had been exposed previously in the lexical-decision task. For other phase 3 questions, both old and new, their answers were target words not exposed earlier in the lexical-decision task. Thus, our experimental design incorporated two crossed independent variables: question type (old or new), and target-word type (previously exposed or unexposed). For each possible combination of these variables, we measured the probability with which the subjects successfully produced the correct answers to the phase 3 questions.

**Rationale**

The rationale of this experiment is straightforward. Although our general-information questions were less complex than some of the problems discussed previously, they nevertheless posed a problematic situation for our subjects and led them to occasional initial impasses. Also, because the subjects presumably had stored knowledge relevant to the domain of each question, we would assume that they were, in principle, prepared to assimilate further relevant information after the impasses occurred.

Consequently, our hypotheses about predictive encoding and opportunistic assimilation make some specific predictions about the subjects' performance in phase 3 of the experiment. For example, consider what should happen with old questions presented again during this phase after prior exposure to relevant target words in the intermediate lexical-decision task of phase 2. In this case, we would predict that performance ought to improve significantly compared to what happened in phase 1, because of the beneficial assimilation process mediated by previously stored failure indices. On the other hand, for old questions whose target-word answers were not exposed during the lexical-decision task, we would make a different prediction. The improvement in answering them ought to be much less; in fact, correct answers to them might occur no more frequently than for new phase 3 questions, because in neither of these cases would subjects have a chance to benefit from opportunistic assimilation of the previously exposed correct answers.

At the same time, the method of experiment 1 also provides a potentially strong test of other alternative hypotheses about the source of incubation effects. Suppose incubation facilitates future problem solutions by allowing the strengths of subliminal stored memory traces to grow passively and spontaneously after they are stimulated by an initial unsuccessful problem-solving attempt (e.g., see Bowers et al., 1990). Then even when the target-word answers for questions from phase 1 are not exposed during phase 2, one might still expect performance on these questions to improve during phase 3 because of increased memory-trace strength. By looking for the presence of such improvement, we can test the validity of the latter expectation and the hypothesis from which it stems.

## Results

Consistent with these predictions, some results from experiment 1 appear in figure 3.4. Here the top graph shows what happened during phase 3 of question answering on day 2 when approximately a half hour separated the first and second phases of day 1. On the vertical axis is the percentage of cases in which a question was answered correctly in phase 3. On the horizontal axis is the type of question involved (i.e., old ones presented previously in phase 1 or new ones presented for the first time in phase 3). The shading of the vertical bars indicates whether the target-word answers to these questions were exposed or unexposed in the intermediate phase 2 lexical-decision task.

From the top graph, two key results are apparent. First, for old questions, the percentage of correct answers during phase 3 was significantly greater when their target words were exposed previously during phase 2 than when they were not (dark versus light bars on left). In fact, virtually all of this benefit can be attrib-



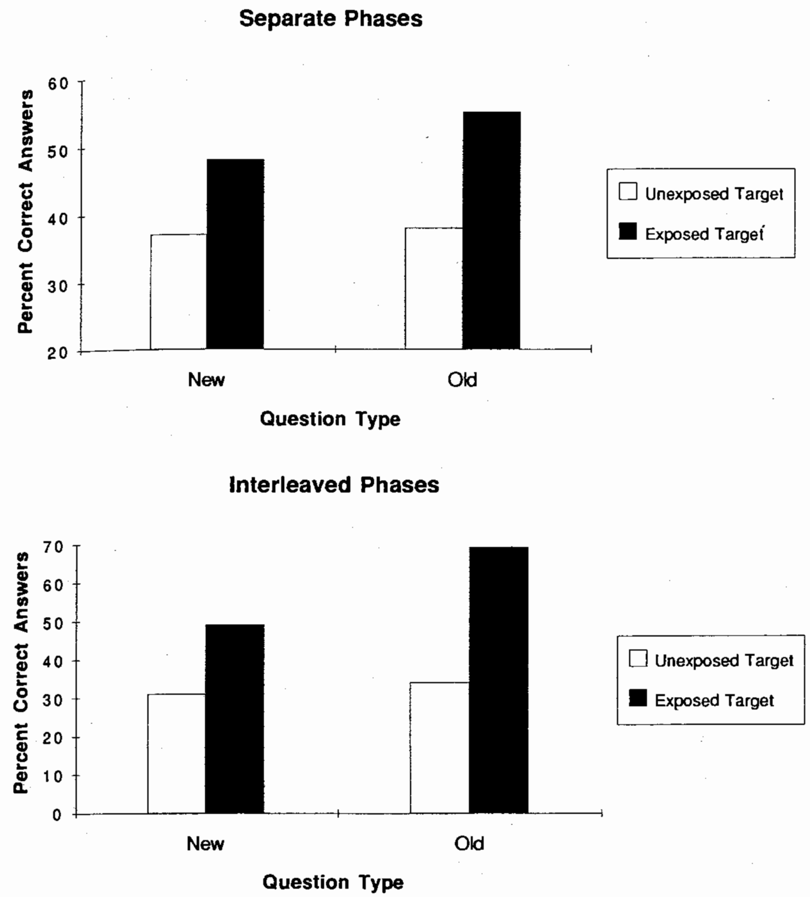



**Figure 3.4**
Results of experiment 1 with the problematic general-information questions. The vertical axis shows the percentages of general-information questions correctly answered during phase 3 of the experiment. The horizontal axis shows different types of questions that were involved, including old ones whose answers were attempted during phase 1 and new ones not attempted previously. The dark and light bars correspond respectively to cases for which the correct target-word answers were or were not exposed during phase 2, the intermediate lexical-decision task. (For more details, see text; also see Meyer, Yaniv & Davidson, 1988; Yaniv, Meyer & Davidson, 1993.)

uted to cases in phase 3 where the subjects successfully answered old questions on which they had previously failed in phase 1. This is exactly what our opportunistic-assimilation hypothesis would predict; benefits toward resolving a prior problematic situation accrue if and only if an impasse has occurred before and been followed by further incidental relevant information.

A second interesting result in the top graph of figure 3.4 concerns performance on the old versus new questions during phase 3. When the relevant target-word answers were not exposed during the lexical-decision task of phase 2, subjects were no more accurate at answering the old questions than at answering the new ones (right and left light bars). Their further attempts to answer old questions on which they had failed before benefited hardly at all from the intervening incubation phase if the relevant target words were not exposed there. In other words, the subjects manifested no spontaneous improvement on initially failed questions. Once again, this is what we would expect if incubation effects stem primarily from interactions with external cues after an impasse has been reached rather than from a continuation of passive covert conscious or subconscious processing of the sort associated with fatigue dissipation, selective forgetting, and random reorganization in long-term memory.

Further supporting these conclusions, the bottom graph of figure 3.4 shows a pattern of results similar to the top graph except that the interactive effects of question type (old versus new) and target-word type (exposed versus unexposed) are even greater. We obtained this enhancement simply by interleaving phase 1 (initial attempts at question answering) with phase 2 (target-word exposure in the lexical-decision task). Given such interleaving, subjects had to wait less before being exposed to further relevant information after each impasse at question answering. As a result, their traces of prior impasses were presumably stronger at the time of the subsequent beneficial target-word exposures, thereby facilitating opportunistic assimilation.

Yet the latter outcome does not mean that the traces of prior impasses depend solely on temporary residual spreading activation in networks of long-term memory. We found no evidence of any activation in the phase 2 lexical decisions when a relatively long interval separated the exposed target words from the initial



question-answering attempts in phase 1. This is consistent with the results of some other investigators (Connor, Balota & Neely, 1992). However, subjects' question-answering accuracy in phase 3 still showed a significant interaction between question type and target-word type under these circumstances (figure 3.4, top graph). It therefore appears that opportunistic assimilation is, as proposed earlier, triggered by reaccessing stored failure indices distinct from and more permanent than residual spreading activation per se (see Meyer, Yaniv & Davidson, 1988; Yaniv, Meyer & Davidson, 1993).

Finally, the importance of failure indices for opportunistic assimilation is likewise demonstrated by another result from our studies. In an extension of the method described here, we replaced the question-answering task of phase 1 with a sentence-verification task (Davidson, 1993). Following this replacement, additional groups of subjects made true-false decisions about sentences of the form, "A sextant is a nautical instrument used in measuring angular distances, especially the altitude of the sun, moon, and stars at sea," which were presented in phase 1. Then, in subsequent phases 2 and 3, our procedure was exactly the same as before; the subjects made a series of lexical decisions about various target and control words, after which they attempted to answer various general-information questions on the next day.

Under these latter conditions, we found no evidence of interactions analogous to those in figure 3.4. Again, this is exactly what our opportunistic-assimilation hypothesis would predict. Because the first phase of our latter method involved no initial impasses (i.e., no failed question-answering attempts in phase 1), we would not expect any stored failure indices to be present in memory at the time of the phase 2 lexical-decision task and, without these, subsequent exposure to relevant new information, as provided by the intermediate target words, would have no future benefit when the problematic questions are later encountered in phase 3 (see Adams et al., 1988; Lockhart et al., 1988; Needham & Begg, 1991).

### Conclusions

In summary, the results of experiment 1 support our hypotheses about processes that may underlie insightful performance in problematic situations. We found strong empirical evidence of the important role played by initial impasses, stored failure indices, and opportunistic assimilation of information from subsequent external exposures to relevant information. On the other hand, the present study yielded no evidence of covert passive mechanisms (e.g., spontaneous growth of activation in stored memory traces) that have sometimes been proposed as principal mediators of incubation effects and insight.

### Experiment 2: Remembering Failed Solution Attempts

Our second experiment was designed to test another major prediction derived from the opportunistic-assimilation hypothesis (Seifert & Patalano, 1991; Patalano & Seifert, 1993). According to it, people should have especially accessible memories of problems whose initial confrontation ends with an impasse (i.e., failure to reach solution). This prediction follows from two complementary assumptions of the hypothesis: (1) At the time of impasse, indices of the failure are stored in memory, pointing back to it and other associated episodic information; and (2) working on a problem until reaching impasse maximizes the likelihood that all currently available information will be encoded and used to store a stable, albeit partially incomplete and perhaps strained, representation of the problem situation. To the extent that these assumptions hold, a problem solver will have more avenues along which to re-access the problem subsequently than would be the case if initial processing terminates (e.g., is interrupted) prematurely before an impasse is reached. We would therefore predict that, under at least some circumstances, people's probability of recalling prior problems should be greater for failed ones than for successfully completed or merely interrupted ones.

Interestingly, some previous evidence concerning this prediction has been obtained already in a classic experiment by Zeigarnik (1927), who gave subjects a set of various tasks to perform, including arithmetic problems, puzzles, and manual construction activities (e.g., making cardboard boxes). During their performance of half these tasks, the subjects were interrupted before they had finished them, whereas they were allowed to complete the other half of the tasks. After each task was attempted once



by the subjects, they next performed a free recall in which they reported as many of the previous tasks as they could. Zeigarnik found that the probability of recall was substantially higher for the interrupted tasks than for the uninterrupted tasks. The positive interruption effect on recall has since become known as the *Zeigarnik effect* (Baddeley, 1976). It is consistent with our prediction that failed problem-solving attempts may be remembered better than successfully completed ones.

However, in subsequent attempts to replicate and extend Zeigarnik's original results, the relatively high probability of recalling interrupted problems has not always been found. For example, after a careful review of the literature, Van Bergen (1968) claimed less than half of the replication attempts successfully obtained the Zeigarnik effect. This disappointing outcome could perhaps be taken as evidence against the effect's robustness and our hypothesis's correctness.

Nevertheless, we suspect there may be principled reasons for the previous frequent failures to replicate the Zeigarnik effect. In particular, many of them may have involved interrupting subjects during their problem-solving attempts *before* they had reached an impasse. If so, then the interruptions may have occurred before subjects had formed stable partial mental representations of the problems and associated them with failure indices. Under these latter circumstances, we would not predict relatively high recall probability for the interrupted problems. On the contrary, our opportunistic-assimilation hypothesis would predict that problem solving interrupted before impasse might well yield poor recall, because the reaccess pathways back to the problem would not yet be in place. Thus, it is not necessarily surprising that past experimenters, insensitive to the importance of reaching impasse, failed in their attempts to replicate the Zeigarnik effect; perhaps they merely interrupted their subjects too soon.

To test this conjecture and to assess the memorability of problem impasses versus problem interruptions, we conducted an analog of Zeigarnik's (1927) original experiment, but we carefully controlled the nature and timing of the circumstances under which problem solving was interrupted (for more details, see Patalano & Seifert, 1993; Seifert & Patalano, 1991).

## Method

The experiment involved three different groups of subjects, each of which participated in two successive phases of testing. During phase 1, we gave subjects a series of 20 or more word problems to solve, one by one. Each problem was presented on a separate sheet of paper, and the subjects were supposed to write a solution as quickly and accurately as possible. The problems came from *The Puzzle School* by Mosler (1977) and consisted of various mathematical, logical, and insight puzzles; for example, "What is the largest sum of money in current U.S. coins (but no silver dollars) that a person can have in his pocket without being able to give someone change for a dollar, half-dollar, quarter, dime, or nickel?"

We chose the problems for phase 1 to represent a range of difficulty levels, as determined from a preliminary pilot study. Virtually all of them could be solved within 5 minutes or less by most college students. However, few could be solved within less than 30 seconds, and many caused subjects to experience an intermediate temporary impasse approximately 30 to 60 seconds after a solution attempt started.

At the end of phase 1, the subjects entered the second phase of the experiment. During it, they performed a free-recall task in which they tried to recall all of the problems on which they had worked in phase 1. For each problem recalled, a brief written description of the problem's details was produced. There was no constraint on the order of these descriptions. By examining the content of these reports, we scored the average number of problems that the subjects recalled correctly as a function of the test group in which they participated.

The three different groups of subjects performed under three different problem-solving conditions during phase 1. For one group, the first phase involved a *timed-interruption condition.* Here we let the subjects work on half of the problems until they solved them successfully, which typically took less than a few minutes per problem. During the subjects' attempts to solve the other half of the problems, we interrupted them on each one approximately 30 seconds after the solution attempt had begun, at a point where they seemed well engrossed in their effort but before they had succeeded or reached an impasse. The interrupted and uninterrupted



problems were interleaved randomly, so the subjects could not predict exactly whether or when an interruption might occur.

For a second group of subjects, phase 1 involved an *untimed-impasse condition.* The circumstances associated with it were somewhat different from the preceding condition. Here we let subjects work through the series of problems at their own pace for a total of 50 minutes. They were told to work quickly and accurately, and to complete as many problems as possible within this period. For problems that seemed relatively difficult, the subjects were allowed to give up at least temporarily and go on to the next one. They were also encouraged to write down any partial or complete solutions that they produced along the way. This then created a situation in which unfinished problems would likely be left in a state of impasse.

The third group of subjects performed under a *timed-impasse condition.* In this group, the amount of time that the subjects spent on each problem was strictly controlled; it equaled 1 minute per problem. Minute by minute, we gave the subjects one new problem after another. For each one, they were again supposed to write down complete and partial solutions along the way. Because of how the problems varied in terms of their intrinsic difficulty, this procedure helped ensure that the problems for which the subjects did not achieve complete successful solutions would be left in a state of impasse. The timed-impasse condition therefore let us equate how long subjects spent on solved and unsolved problems, while maximizing the chances that impasses were reached for the unsolved problems. Of necessity, such control was not possible in the previous two conditions (i.e., timed interruptions without impasses and untimed impasses), but this third condition helped overcome the inherent confounding associated with them.

## Rationale

If our assumptions that underlie the opportunistic-assimilation hypothesis are correct, and if our conjecture about the causes of previous failures to replicate the Zeigarnik effect are correct, then three related results should emerge from experiment 2. In the timed-interruption condition, which does not allow subjects to reach impasse and store failure indices for interrupted problems, their ultimate free recall should be greater for the solved problems than for the unsolved problems. On the other hand, in the untimed-impasse condition, the recall rate should be higher for the unsolved problems, because subjects are allowed sufficient time to reach impasse and to store stable partial problem representations along with associated failure indices, which then enhance subsequent retrieval. Furthermore, the latter pattern of results should carry over to the timed-impasse condition, because the same beneficial memory storage will be possible there too, even though the time spent on solved and unsolved problems is equated. Our hypothesis predicts that recall performance will not be simply a function of the amount of time spent on a given problem.

**Results**

Some results of experiment 2 appear in figure 3.5. Here we have plotted the subjects' average percentages of problems recalled in phase 2 (vertical axis) against the condition under which they performed during phase 1 (horizontal axis). The light and dark vertical bars indicate the recall rates for solved and unsolved problems, respectively, in each condition.

As can be seen from figure 3.5, all the results here supported our predictions about circumstances surrounding the Zeigarnik effect. When subjects were interrupted in their problem solution attempts before reaching impasse (timed-interruption condition), the rate of subsequent problem recall in phase 2 was actually greater for solved problems than for unsolved problems (lefthand pair of vertical bars). In contrast, when subjects were allowed to reach impasse in either a self-paced fashion (untimed-impasse condition) or in an experimenter-paced fashion (timed-impasse condition), the recall rate during phase 2 was significantly greater for unsolved problems than for solved problems (middle and righthand pairs of vertical bars). The similarity of results obtained under the untimed-impasse and timed-impasse conditions shows that the latter superiority of recall for unsolved problems is not caused simply by more time being spent on the unsolved problems before an impasse is reached.



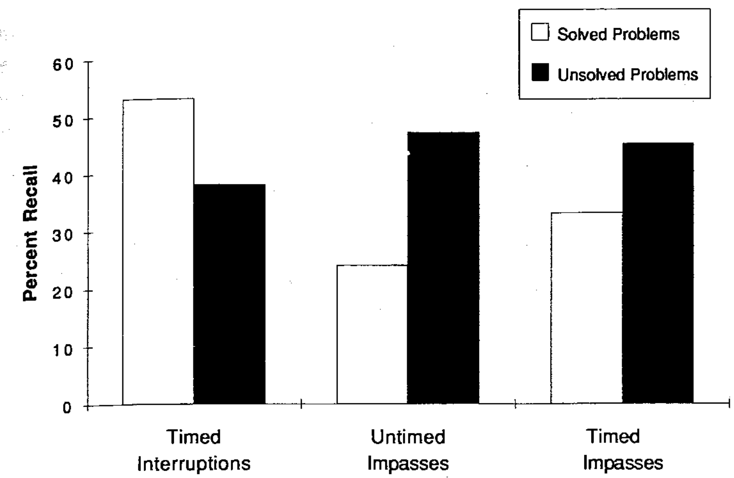



**Figure 3.5**
Results of experiment 2 with the problem-solving and free-recall tasks. The vertical axis shows the percentages of problems that were correctly recalled after an initial phase of problem-solving attempts. The horizontal axis shows various conditions under which these attempts occurred. The light and dark bars correspond respectively to recall performance for solved and unsolved problems. (For more details, see text; also see Patalano & Seifert, 1993; Seifert & Patalano, 1991.)

Further support of the latter conclusion comes from additional analyses of the results in the untimed-impasse condition, where subjects controlled how much time they spent in trying to solve each problem. After factoring out the times spent on various problems there, and after submitting the recall rates to a multiple-regression analysis with both solution state (solved or unsolved) and solution-attempt duration as independent predictor variables, we still found that the solution state mattered; predicted recall remained higher for problems on which the solution attempts reached impasse.

**Conclusions**

As we predicted, experiment 2 shows that unsolved problems are more available in memory than are solved problems but only under some specific circumstances. This is consistent with both

Zeigarnik's (1927) results, and subsequent occasional failures to replicate them (Van Bergen, 1968). Most importantly, our research identifies subject-generated impasses and failures in solution attempts as crucial to enhanced memory for past problems. Such memory enhancement apparently stems from the cognitive effort, trace consolidation, and failure indices associated with pursuing solution attempts until impasse is reached. As a result, the greater availability of unsuccessful solutions in memory could significantly promote their later participation in the achievement of ultimate insight.

Interestingly, however, there is one caveat that should be appended to this latter conclusion. In a further extension of the results from experiment 2, we increased the rate at which subjects failed to solve the problems presented under the timed-impasse condition. This involved including more relatively difficult problems. With the latter change, subjects' failure rate increased from roughly 30 percent to well over 50 percent. As a result, the relatively high memorability of the failed solution attempts dropped and became approximately equal to that for the successful attempts. It may be that people have limited capacity or limited motivation for selectively storing, retaining, and retrieving unsolved problems on which impasses have been reached. Perhaps when the human information-processing system becomes overwhelmed with too many problems, its otherwise efficient handling of them deteriorates. Consequently, the attainment of insight may require that the creative individual not be too overburdened with unsolved pressing problematic situations.

### Further Implications of the Present Experiments

Taken together, the combined results of experiments 1 and 2 provide an integrated characterization of the processes underlying insight. This is especially gratifying given that the methods used here involved rather different tasks—namely, answering general-information questions on the basis of knowledge stored in long-term memory (experiment 1) and recalling novel word problems (experiment 2). Because of these differences, the ways in which solutions were reached, and the causes of failures when they were not, varied significantly across the two experiments. For



example, in experiment 1 with the general-information questions, the subjects' task required activating prior "solutions" (i.e., target-word answers) already stored in memory, and failures presumably resulted from a lack of access to necessary information at the time of the initial solution attempt. On the other hand, in experiment 2 with the novel word problems, subjects had to construct their solutions from scratch rather than retrieving them from memory, and failures at solving the word problems stemmed from an initial inability to finish the construction of a new solution. Nonetheless, as summarized already, the results of the two experiments complement each other nicely and lead to similar conclusions.

Such congruence implies that the inferences drawn from our research are perhaps applicable to a variety of domains involving insight. It also seems, on the basis of what we found, that studies of insight may be best pursued through a variety of empirical methods. The question-answering experiment allowed a controlled test of exposure to external information; presumably, the results from it will generalize to other problem-solving situations. Similarly, the problem-recall experiment showed that later access to failed problems is relatively high, which may likewise have occurred in the question-answering experiment during the subsequent target-word exposure phase. These diverse considerations bode well for future investigations that vary in their details and scope but that all strive toward a unified characterization of insight phenomena.

## TOWARD AN INFORMATION-PROCESSING MODEL OF INSIGHT

On the foundation laid in preceding sections, we may now complete this chapter by taking steps toward a more comprehensive model of the mental processes that lead to cognitive insight. As shown already, our opportunistic-assimilation hypothesis and expansion of the prepared-mind perspective account well for the phenomenological characteristics of insight, anecdotal cases, and laboratory data. The present account can therefore help to update and elaborate Wallas's (1926) original analysis. In what follows, we pursue this elaboration to its natural conclusion, outlining a model with several component stages and substages that parallel the preparation, incubation, and illumination phases proposed by Wallas and that fully encompass our own current theoretical views as well.

### Substages of the Preparation Phase

The first stage of the present model concerns details of the information processing that takes place in the minds of individuals during the initial preparation phase of problem solving. According to our current views, stage 1 includes four major substages: stage 1a, confrontation with a problem; stage 1b, construal of failure; stage 1c, storage of failure indices in long-term memory; and stage 1d, suspension of initial processing. We assume that in order for preparation to maximize the likelihood of future insightful outcomes, all these substages must be completed before a problem solver moves on to deal with other matters.

#### Stage 1a: Confrontation with a Problem

Obviously, if ultimate insight is to occur in resolving a difficult problematic situation, the problem first has to be taken seriously and confronted head-on. The would-be problem solver needs sufficient motivation to spend significant amounts of time on an initial careful analysis of the problem situation, pushing ahead as far as possible with it, forming a coherent memory representation of the problem, and using all the available information in a solution attempt. Without these prerequisite investments, there can be little hope of later success. In this respect, we agree with other previous theorists who have stressed the importance of problem analysis and mental representation as part of preparation for insight (e.g., Kaplan & Simon, 1990; Keane, 1989; Ohlsson, 1984b).

#### Stage 1b: Construal of Failure

A second key substage of preparation in our nascent model is a construal of failure at the end of an initial problem-solving attempt. When an impasse has been reached, it must be deemed such in order that special facilitative memory traces of the impasse (i.e., failure indices) get properly stored. As we have shown through our laboratory studies (Experiments 1 and 2), mere interruption of problem-solving activity by itself promotes neither subsequent enhanced recall nor opportunistic assimilation of relevant new information.



This demonstration implies that under many circumstances, insight in problem solving is unlikely to occur. For example, a problem (1) may not be noticed as such, (2) may be noticed but not attempted, (3) may be attempted but not understood well enough to identify a specific cause of failure, (4) may be understood but interrupted en route to its solution, or (5) may be solved incorrectly but without the problem solver's realizing it. Under the present theoretical analysis, any of these eventualities would fall short of what must happen during preparation to lay the groundwork for later insight.

That serious problem solvers are aware of failure and take account of it is documented by some additional results from our two experiments. In the word-problem study (experiment 2), for example, we collected subjects' confidence ratings after each problem. They were highly correlated with the accuracy of the subjects' solutions (correct, incorrect, or incomplete) and with later free recall. Problems for which subjects had low confidence about their solutions were more likely to be recalled later. Also, in the untimed-impasse condition, where subjects controlled how long they spent on each problem, much more time was spent on problems ultimately left unsolved. Similarly, in the study with answering of general-information questions (experiment 1), subjects spent more time on questions for which the answer was ultimately not recalled, especially when they had a high "feeling of knowing" about it. This may mean that failure is, ironically, most intense when success seems tantalizingly close at hand. It therefore appears that subjects do indeed distinguish their failures from successes, suggesting an awareness on their part that impasses are important.

This then raises a further interesting question: On what basis do problem solvers decide that an initial impasse has been reached and that the preparation phase should be deemed a failure? Although we cannot answer the question for certain, at least two possibilities come to mind, inspired by analysis of stopping rules in other domains of information processing (Meyer, Irwin, Osman & Kounios, 1988). One is that subjects have a preset notion about the maximum amount of time that problems of a particular type should take to solve and, once they have reached this maximum, they declare an impasse. Another possibility is that they declare an impasse when they have exhaustively used, as best possible, all available components of the problem situation but without achieving full success. As indicated by our results concerning feelings of knowing (experiment 1), impasses may be declared even when success seems tantalizingly close at hand.

**Stage 1c: Storage of Failure Indices in Memory**

Whatever the criterion for declaring an initial impasse, the next substage of our model for the preparation phase of creative problem solving involves storing failure indices in long-term memory, marking the episodic information associated with the problem and the first attempt to solve it. Following proposals by other cognitive scientists (e.g., Hammond et al., 1991), we assume that the failure indices are special markers, distinct from the general heightened activation level that the problem episode may leave (see Anderson, 1990). The purpose of storing the failure indices is, of course, to help guide the problem solver back to the problem when relevant new information is later encountered externally during subsequent ongoing perception and comprehension.

We assume that the failure indices associated with an initial problem-solving impasse may remain present and useful in long-term memory for hours, days, weeks, months, and even years if the impasse has great significance for the stymied problem solver. This may, for example, have been so with Albert Einstein, the inventor of the theory of relativity, who during the last half of his life made an exerted long-time effort to unify the laws of gravitation and electromagnetism but without success (Crease & Mann, 1986). Although our own experiments extended over just a 24-hour period, they too provide some evidence for the endurance of problem failure indices. In experiment 1 on answering general-information questions, these indices lasted significantly longer than the residual memory activation induced by processing the questions initially, as revealed by a comparison of subsequent effects on lexical-decision reaction times versus the probabilities of ultimate correct answers.

Another key characteristic of the stored failure indices for a problem-solving impasse is that they may be integrated with other general knowledge in long-term memory. Our study with the



question-answering task suggests this possibility because information presented there within a separate context (the lexical-decision task) was nevertheless recognized and used to overcome prior retrieval failures. If the stored failure indices were separate from the rest of memory, then exposure to relevant information in other contexts would seem less likely to resurrect them. That traces of failures may be accessed across various tasks is especially interesting, given previous pervasive findings of little or no information transfer between different task domains. Perhaps stored failure indices have a unique status for promoting such transfer (see Adams et al., 1988; Lockhart et al., 1988; Needham & Begg, 1991).

**Stage 1d: Suspension of Initial Processing**

With potentially beneficial failure indices stored away, the last substage of the initial preparation phase may ensue. In our model, we assume that stage 1d simply involves a suspension of information processing for the problem at hand, after which the problem solver may go about his or her other business. This then leads to the next phase, incubation, and its various substages that precede insight.

## Substages of the Incubation Phase

According to our current views, stage 2 includes three major substages: stage 2a, intermediate incubation during other activities; stage 2b, exposure to new information; and stage 2c, retrieval of failure indices. We assume that as precursors to future insightful outcomes, all these substages must be completed, just as are those of stage 1.

**Stage 2a: Intermediate Incubation**

The present model makes some interesting specific claims about what happens during intermediate incubation while the problem solver engages in other activities. Under our assumptions, the sheer passage of time has no bearing per se on whether the problem solver ultimately will achieve illumination and insight. We do not attribute insight to spontaneous subconscious processes that could conceivably occur as part of the incubation phase. As mentioned already, the opportunistic-assimilation hypothesis discounts the roles played by processes that involve growth of subliminal memory-trace activation (Bowers et al., 1990), selective forgetting of inappropriate memory traces (Silveira, 1971), and covert random reorganization of knowledge structures. Rather, in our view, the main contribution of the incubation phase is simply to provide the problem solver with incidental exposures to various external stimuli, some of which may be relevant for resolving prior problematic impasses. If the present model is correct, until such exposures occur by chance, the problem solver, in essence, would do no further work on a problem.

Although these are somewhat extreme claims, there is evidence from our research to support them. In particular, Experiment 1 on answering general-information questions revealed no evidence of spontaneous growth in memory-trace activation during an intermediate incubation phase. The incubation phase was beneficial only when it provided exposures to relevant new information—namely, the target-word answers for previously failed questions. This outcome has some potentially significant implications for ways in which insightful problem solving might be facilitated. If our conjectures are correct, then taking regular extended breaks from working on hard problems is well advised but will be most effective if the breaks involve other stimulating activities. Shifting back and forth among tasks, including recreational and unstructured ones, may increase the chances that a stymied problem solver will be exposed to relevant new information. Staying in an old environment, on the other hand, is less likely to provide occasions for such exposures.

At the same time, however, we would not want to dismiss entirely the importance of internal self-driven processes as a part of incubation. Internal processing could conceivably generate new problem-relevant information that promotes insightful solutions, supplementing external encounters with such information. For example, this might happen during the course of dreaming, which in essence simulates external events and stimulus encounters. If an internal dream-based incubation mechanism does exist, its products—just like externally obtained information—could interact beneficially with failure indices stored in long-term memory, thereby leading to insight. The line between illusion, hallucination, and reality may be a thin one.



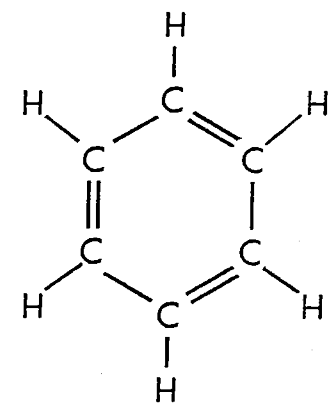



**Figure 3.6**
The benzene ring discovered by Kekulé through opportunistic assimilation of self-generated perceptual stimulation while dreaming. (See text for further details.)

To be specific, consider the following anecdote, which concerns how the ringlike molecular structure of the organic compound benzene was discovered by the chemist Kekulé (Koestler, 1964, p. 118; cited in Glass & Holyoak, 1986, p. 413):

> I turned my chair to the fire and doze.... Again the atoms were gamboling before my eyes.... My mental eye ... could now distinguish larger structures, of manifold conformation; long rows, sometimes more closely fitted together; all twining and twisting in snakelike motion. But look! ... One of the snakes had seized hold of its own tail, and the form whirled mockingly before my eyes. As if by a flash of lightening I awoke.

Apparently what happened here was that Kekulé stimulated himself with new perceptual information through dreaming. His image of the snake seizing its own tail, which closely parallels the actual structure of the benzene ring (figure 3.6), led to opportunistic assimilation and the eventual proposal of the benzene ring.

**Stage 2b: External Exposure to New Information**

Be this as it may, the present model still maintains that external exposure to new information from the environment is a principal source of insight. We assume that such exposures, and the opportunities for having them, are what make an intervening incubation phase especially helpful. Our assumption is strongly supported by both the anecdotal cases considered previously and by the laboratory experiments reported here. In the question-answering task of experiment 1, for example, we found that a single subsequent exposure of a target-word answer after an initial question-answering failure was sufficient to increase substantially the probability of a later successful answer (see figure 3.5).

This outcome raises some further interesting questions about exactly which kinds of new information may promote insight. For new information to be helpful, what sorts of relationships must it have to an original problematic situation and the memory representation formed thereof? In answer to this question, there is at least one more discovery we have made: External stimulus cues that are related to the goals of a problem solver's pending solution plans are more likely to remind him or her of those plans than are other types of cue (Patalano, Seifert & Hammond, 1993). Even if the goal-related cues are relatively abstract, they may still be beneficial (e.g., seeing a piece of gum can effectively remind a problem solver about the goal of rehanging a wall poster, just as can seeing a metal tack). Thus, future researchers may wish to focus more closely on how different possible relationships between new information and past solution failures can contribute to insight.

### Stage 2c: Retrieval of Failure Indices

Under the present model, the incubation phase would culminate when an exposure to relevant new information triggers the access of failure indices associated with a prior problem-solving impasse. We assume that this triggering takes place during the course of normal perception and comprehension processes that the problem solver uses in dealing with all incoming stimuli. Hence, the final steps on the road to insight may well be subconscious, as perception and comprehension processes usually are. People do not typically become aware of how they perceive or comprehend the environment; all they consciously know is that the products of these processes often seem natural.

Again, our assumptions are consistent with results from previous research. In experiment 1, for example, the lexical-decision task given to subjects during the intermediate incubation phase presumably required some of the same retrieval and comprehension processes used in understanding ordinary language (Meyer & Schvaneveldt, 1971). As we would predict, these processes were sufficient for the failure indices associated with prior unanswered questions to be accessed, and they facilitated opportunistic assimilation of the target-word exposures provided by the lexical-decision task.



## Substages of the Illumination Phase

The third stage of the present model concerns details of the processing that takes place during the illumination phase of problem solving, after relevant new information has been encountered in the external environment and previously stored failure indices have been accessed. According to our current views, stage 3 includes two major substages: stage 3a, information interpretation and assimilation, and stage 3b, *insight*! We assume that in order for an encounter with new information to have its full beneficial effect, both of these substages must follow the incubation phase and bring it to final fruition.

### Stage 3a: Interpretation and Assimilation

On an encounter with relevant new information, stage 3a begins when contact is made with previously stored failure indices. At this point, normal progress on automatic perception and comprehension processes, which lead incidentally to access of the failure indices, may be interrupted in the same way as high-priority external inputs cause temporary suspension of information processing by time-shared computer-operating systems. After such interruption, our opportunistic-assimilation hypothesis claims that other special problem-solving processes take control to interpret the newly encountered information in light of its potential relevance for past problems. This would presumably involve assessing how the new information fits with, and perhaps overcomes, the particular block(s) that caused earlier solution attempt(s) to be construed as failures. If the latter assessment reveals that the new information can help make progress on the problem and perhaps yield an immediate solution, then under the present model, the new information would be assimilated into the original mental representation of the problem. Also, if need be, problem restructuring (i.e., accommodation of the new information) could occur at this point (see Kaplan & Simon, 1990; Keane, 1989; Ohlsson, 1984a, 1984b).

The steps associated with implementing the assumed interpretation and assimilation processes are crucial ones. They may require lots of attention on the part of the problem solver and induce a significant increase of his or her physiological arousal level (e.g., increases of heart rate, blood pressure, breathing, and neural activity). Increased arousal and the heightened emotions that accompany it can help to focus attention on resolving a previously failed problem and on learning from the opportunity presented by the current exposure to relevant new information (Baddeley, 1976). In effect, the accompanying emotional experience provides an explicit flag that an important event is at hand and that extra effort should be exerted immediately to gain the most benefit from it. Moreover, the increased arousal could amplify the positive reinforcing affect that the problem solver experiences, making it more likely that he or she will seek additional future insights. As we have seen already in the introspective reports by Richard Feynman and others, stage 3a—the act of interpreting and assimilating long-needed and highly important information—can be extremely exciting and gratifying.

### Stage 3b: Insight

With the present model, insight comes finally at the end of the illumination phase, stage 3b. It yields two major products: (1) an improved representation of an important previously unsolved problem, which now likely contains the essence of a correct solution; and (2) the delightful "Aha!" experience colored by an increased physiological arousal level with positive affective overtones, which further facilitates opportunistic assimilation and long-term memory consolidation.

## Conclusions

In summary, the present model incorporates some normal mental processes and so partly adheres to the business-as-usual perspective on the nature of insight. At the same time, our theoretical assumptions highlight two relatively special mechanisms that instantiate the prepared-mind perspective and that help explain how intellectual magicians perform their insightful tricks without recourse to supernatural mental powers. One special mechanism proposed here relies on failure indices in long-term memory to mark problem-solving impasses. These indices are clearly crucial for intelligent problem solvers who want to achieve their goals but are nonetheless human and therefore subject to disappointments in their initial solution attempts. A second special mechanism proposed here relies on opportunistic assimilation to benefit from encounters with relevant new information, once a prior problem has been reaccessed through the stored failure indices. Because such opportunism gets only occasional chances to take control, it must wait in the wings against a backdrop of ongoing normal processes.

Although our own theoretical ideas may not seem entirely complete yet, we hope that whatever limitations they have at present will at least enable the storage of further helpful failure indices in the minds of this book's readers. We likewise hope that readers' future encounters with other relevant information-processing concepts will trigger subsequent insightful opportunistic assimilation. If so, then perhaps someday all of us will come to understand EVVVVVERYTHING there is to know about the nature of insight!



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