

Cognition and the Creation of Ideas

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Abstract

The cognition that gives rise to creative thinking is not a singular process or operation; rather, it consists of many different cognitive structures and processes that can collaborate in a variety of ways to construct different types of creative products. Cognition that is often relevant to creativity includes remote association, conceptual combination, visualization, retrieving and mapping analogies, reasoning, insight problem solving, implicit and explicit cognition, abstraction, and mental models.

Key Words: creativity, cognition, insight, imagination, emergence

How do our minds produce creative ideas? Clearly, there can be no formulaic answer to this enormous question. Part of the problem is that a consensual definition of creativity is difficult to construct. There are many domains of creative endeavor, such as art, engineering, literature, business, or athletics, and creativity might systematically differ for different domains. Furthermore, even within a single domain there are usually many different ways that creative ideas come into being. Even a single individual can be creative in different ways at different times. To know how our minds produce creative ideas, we undoubtedly need to understand the many factors that affect creativity, and there are multiple approaches to understanding those factors. For example, motivational factors, emotional factors, individual differences, environmental factors, and historical factors can strongly influence creativity. One of those factors, clearly, must be cognition: Creativity is at least in part influenced or even determined by cognition. In this chapter we focus on the question of how cognition supports or gives rise to creative work—the *creative cognition* approach.

The creative cognition approach begins with the rather obvious assumption that cognitive processes

play a critical role when people get creative ideas. Creative ideas are ones that are novel and potentially of value. There are similarities among cases in which people have had historically influential ideas, or ideas that are consensually judged as creative. Research in creative cognition is based upon the premise that similar experiences can be evoked in laboratory experiments. Metrics of creativity that emerge from these studies measure aspects of creativity but generally not how creative the ultimate product is. Most who use this creative cognition approach endorse the notion that there is no singular cognitive process or mental operation that we could call *the* creative process. Rather, we manage our cognitive resources in various ways to try to produce ideas with novelty and potential value, and the way those cognitive resources are managed may differ for different domains, different individuals, and different situations. In the course of pursuing creative ideas, people often experience certain phenomena or use certain heuristics to make creative ideas more likely.

We also endorse the notion that the cognition involved in creative activities resembles the cognition

that operates in other areas of cognition that are not commonly considered creative. For example, false memories are created by the same processes that affect creative ideation, analogies are mapped in creative and noncreative cognition, we create language when we speak, and we create mental models of our environments. Novel and useful outcomes emerge in many domains of cognition. What is special about creative cognition is that the insights and ideas produced are usually unexpected (e.g., Metcalfe, 1986). The less surprising the product, the less creative it seems to be; nonobviousness is a requirement of all U.S. patents (Smith, 2008). Furthermore, unexpected insights and ideas that have value prompt the experience of delight. Although it engages the same basic cognitive mechanisms involved in domains such as memory, concept formation, problem solving, decision making, and metacognition, creative cognition is not limited to generating planned or deliberately intended products. Truly creative cognition can bring into being unexpected products of delight.

Domains of Cognition Involved in Creative Thinking

There are multiple domains of cognition that are involved in creative thinking, essentially, the same that are involved in noncreative cognition. The most noteworthy of these domains include conceptualization, visualization, memory, problem solving, language, decision making, and several areas of implicit cognition.

Concepts and Categories: The Structures of Imagination

Ward's (1994) structured imagination theory centers on the notion that the ideas imagined by creating minds are based, at least in part, on the conceptual cognitive structures that must be used, extended, and combined during the course of creative cognition. Understanding the ways that concepts are flexibly constructed and tailored for different contexts, how they are combined, and what guides the way that people extend categories in order to recognize or generate new instances of those concepts is essential to this structured imagination view.

Humans acquire vast storehouses of knowledge as a result of their experiences in the world. Because of the centrality of this type of knowledge to what it means to be human, considerable research has been devoted to the nature and structure of our concepts and categories, how they are acquired, and how they guide our actions and thought (Barsalou,

1985; Murphy & Medin, 1985; Rosch, 1973, 1975; Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976; see Rips et al., Chapter 11). Rather than being randomly organized collections of separate pieces of information, concept representations are highly organized and, at least from a functional perspective, hierarchical (e.g., Bower, Clark, Winzenz, & Lesgold, 1969). Both of these properties have implications for understanding the role of cognition in creativity.

Before considering the structured and hierarchical aspects of concepts, it is worth noting that the formation of concepts is itself a kind of creative, or at the very least generative, activity. This is because experiences with entities in the world are discrete, and the structures that tie those experiences together must be generated by the learner. Consider the child who ultimately learns the category "dog" from experiences with the family pet, others seen from the window, in the park, in books, or other places. Each of the experiences occurs at a separate time point, and the "glue" holding them together must be generated by the child. At a more extreme level, even the conclusion that the family pet is really the same entity across multiple discrete exposures is a kind of construction, not given directly by the input. Although this type of construction of conceptual structures is much simpler than those typically thought of when considering creativity, views of creativity are broadening to include a wider range of phenomenon. For example, Kaufman and Beghetto (2009) introduced the *four C* model of creativity to deal with the perceived inadequacy of early suggestions regarding the split between small-c (everyday) and Big-C (eminent) creativity. The latter split does not really allow a distinction between, for example, the songwriting of an amateur amusing himself with simple creations and a professional making her living writing songs, both of which would be small-c creativity, in contrast to the lasting, Big-C works of acknowledged master composers, such as Mozart. Nor does the small-c versus Big-C split allow the type of personally constructed understandings that are developed by individuals as they attempt to make sense of their world to be thought of as creativity, because they may not result in observable products that a qualified audience would judge to be novel and useful. Yet those understandings are clearly an instance of generative thinking. To deal with the latter problem, Kaufman and Beghetto (2009, see also Beghetto & Kaufman, 2007) introduced mini-c creativity to capture the

notion that such personal understandings are a kind of creative construction. By extension, the conceptual structures people generate in service of organizing and understanding experiences can be thought of as instances of creativity, albeit at a very simple level. Thus, Kaufman's four Cs include mini-c (personal realizations), small-c (everyday insights), pro-c (advanced enough to be making a career of some creative domain), and Big-C (eminent contributions to chosen domain).

The fact that our conceptual knowledge is organized and structured into identifiable groupings also relates to another aspect of creativity, namely, the degree to which it is domain general versus domain specific (e.g., Finke et al., 1992). This issue is concerned with the question of whether creative capacity is better thought of as a general ability that could be applied to a wide range of domains or a more specialized ability that would facilitate performance in a single domain. Whether people possess a more general or more specific creativity capacity, the fact is that they create within domains that can be described at various levels of breadth, such as written communication, fiction writing, novel writing, romance novel writing, and so on. To the extent that people possess differing amounts of knowledge and differently structured knowledge about a given domain, a consideration of conceptual structure would seem to favor a domain-specific view of creativity. Certainly, as noted later, domain knowledge will influence the form of newly created ideas within a domain. Alternatively, since some of the basic processes by which concepts are retrieved, combined, and used might represent general cognitive tendencies, a focus on conceptual processing could be readily compatible with a more domain-general view of creativity.

Our organized knowledge structures allow us to function effectively in the world and communicate with others. At a most fundamental level they allow us to identify and correctly classify new entities rather than have to treat each newly encountered object as something novel to be learned about (see Rips et al., Chapter 11). We can readily classify a furry, four-legged, barking, tail-wagging creature with floppy ears dangling from the sides of its head as a dog even if we have never seen it or even another of its breed before because of the stored information we have acquired about previously encountered dogs. Although this capacity for rapid, efficient classification serves us well in most circumstances, it can also underlie our tendency to miss potentially

creative solutions to even the simplest of problems. One classic example of this is the two-string problem, in which would-be solvers must find a way to tie together two strings suspended from the ceiling that are too far apart to be grasped simultaneously (Maier, 1931). Even though a pair of pliers is present that could serve as a pendulum weight for swinging the distant string closer to the one the solver is grasping, most do not readily see that possibility, due at least in part to the efficient tendency to categorize them as pliers rather than as a heavy object. Glucksberg and Weisberg (1966) showed that this so-called functional fixedness effect was prevented somewhat if participants verbally labeled the critical incidental stimulus, adding evidence that categorization can powerfully impact fixation.

The hierarchical aspect of conceptual structure is also important in considering creativity from a cognitive perspective. To illustrate, the same entity could be thought of as a tabby, a cat, a feline, a mammal, a living thing, and so on. Classic research established that, rather than all levels being equally prominent, the basic level, intermediate between the most general and the most specific, tends to predominate in initial classification, labeling and reasoning about a given entity (Rosch, 1973; Rosch et al., 1976; Rosch, 1975). In the example given here, "cat" would be the basic level. The importance of this phenomenon for creativity is that, as described more fully in a later section, the basic level also plays a powerful role in the generation of new ideas within a domain (Rosch, 1973; Rosch et al., 1976; Rosch, 1975).

Our concepts also allow us to go beyond simple classification and to reason and draw inferences about known and novel category instances (Gelman, 1988; Heit, 2000; Osherson, Smith, Wilkie, López & Shafir, 1990; Rips, 1975). Conceptual knowledge includes considerably more information than just that which might be used to classify objects. It also includes known or assumed properties that we can generalize to new instances. Even without seeing the entity described in the previous paragraph, on being told that it is a dog, we would make certain inferences with varying degrees of certainty, including the likelihood that it possessed those identifying properties, as well as a number of others including that it might have a heart, lungs, or a stomach, be someone's pet, go for walks in the park with its owner, eat and drink from bowls, and be susceptible to fleas and heartworms. The extent to which each of those inferences is warranted could be debated, and

considerable research has been devoted to understanding the factors that influence the tendency of people to draw inferences (e.g., Heit, 2000). But such tendencies are also direct determinants of the novelty or unusualness of newly generated products. As noted earlier, people tend to create within domains, and they show a striking tendency to incorporate properties of known domain instances into the novel items they generate (e.g., Bredart, Ward, & Marczewski, 1998; Ward, 1994; Ward, Dodds, Saunders, & Sifonis, 2000; Ward, Patterson, Sifonis, Dodds, & Saunders, 2002) (see Fig. 23.1).

According to the path-of-least-resistance theory (Ward, 1994, 1995), when people develop new ideas, such as designing imaginary life forms, they tend to begin by retrieving highly representative exemplars of creatures, such as a dog, a fish, or a bird. Next, they project the properties of those specific instances onto the novel ideas they are developing. Taking this path of least resistance leads to less original ideas and thwarts more flexible uses of conceptual knowledge. Abstraction can help one avoid this reliance on representative instances, making one more likely to produce creative ideas (Ward & Sifonis, 1997).

Memory

The link between memory and creativity may seem counterintuitive, because memory seems designed to converge upon real events of the past, whereas creativity seems more divergent, dealing with imaginative possibilities. In fact, memory and creativity have much in common, even if the products of memory processes are often quite different from the products of creative cognition. Both creativity and memory involve both conscious and implicit processes, both are sensitive to recent and frequent experiences, both show blocking and recovery effects, and both involve constructive cognitive processes.

Implicit memory is a cognitive resource that supports conscious operations in many ways (see Evans, Chapter 8). For example, in automatization, a repetitious set of operations is offloaded from the explicit system to an automatic, implicit set of processes; this offloading frees up cognitive resources for other attention-demanding activities. Unfortunately, when implicit memory makes inappropriate material too accessible, it can block access to more appropriate information. Worse, this type of block happens without conscious awareness, so it is difficult for one to detect one's own implicit memory blocks. Smith

and Tindell (1997) showed that reading a word (e.g., ANALOGY) that is orthographically similar to the correct completion of a word fragment (e.g., A_L__GY) can cause an implicit memory block for the solution (ALLERGY) (see Fig. 23.2).

Participants who were warned that previously seen blocker words were incorrect solutions still remain susceptible to these implicit memory blocks. Similarly, in creative invention tasks, designers automatically incorporate features of previously seen examples, even when those features are problematic and explicitly forbidden in the instructions (Jansson & Smith, 1991; Landau & Lehr, 2004; Smith, Ward, & Schumacher, 1993). Only when the specific reasons that negative features are problematic are clearly explained to participants is this design fixation effect mitigated (Chrysikou & Weisberg, 2005). Thus, implicit memory of inappropriate material appears to block creative design (see Figs. 23.3 and 23.4).

Another area in which memory and creative cognition share a great deal of overlap involves recovery from blocks. Two mysterious phenomena, *reminiscence* (and the related phenomenon *hypermnesia*) in memory, and *incubation* effects in creative problem solving, have been linked to the same underlying cognitive mechanisms. Reminiscence refers to a phenomenon in which memories that are initially inaccessible are subsequently retrieved without re-exposure to the to-be-remembered material. Hypermnesia, a closely related phenomenon, is a net increase in recall from one recall attempt to the next (e.g., Erdelyi & Becker, 1974). These memory phenomena fly in the face of the long-established rule that memory gets *worse* as the retention interval increases, because time elapses from one test to the next. The mystery of incubation effects is that key ideas for difficult problems sometimes occur when one takes a break from the problem, rather than working on it uninterrupted (e.g., Smith & Blankenship, 1989, 1991). These key ideas are not predictable by the people who experience the moments of insight (e.g., Metcalfe & Weibe, 1987), and they may result from cognitive operations that operate outside of awareness (e.g., Schooler & Melcher, 1995).

Although there are multiple explanations of reminiscence and of incubation effects, and these phenomena may be multiply caused, a single theory has been proposed to explain both. The *forgetting fixation* theory (e.g., Kohn & Smith, 2009; Smith & Blankenship, 1989, 1991) states that both reminiscence and incubation effects can be caused by recovery from initial blocks (i.e., fixation) when

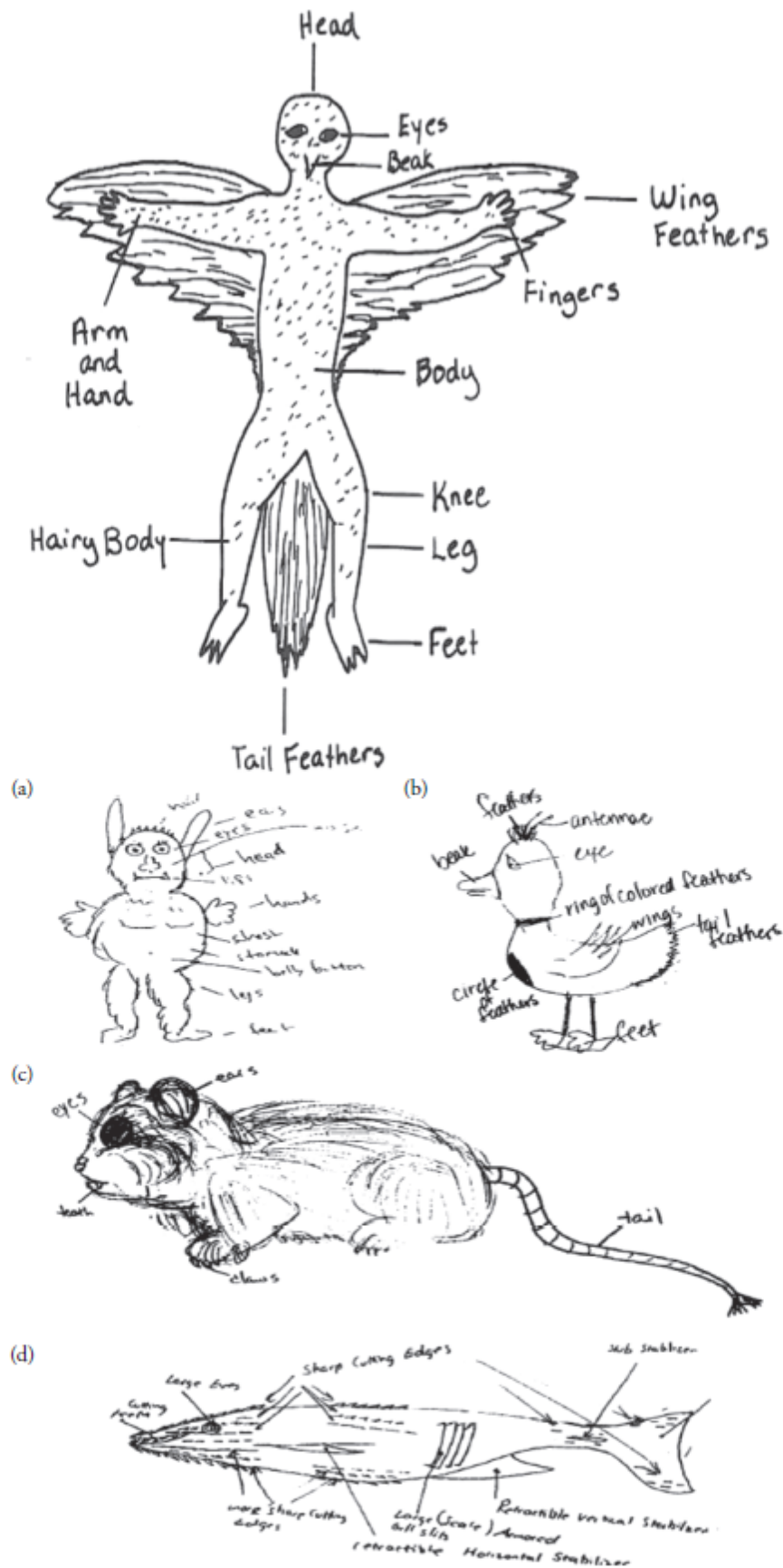


Fig. 23.1 At the top, a novel imaginary creature designed by a participant includes features of known creatures (e.g., head with sense organs, appendages, bilateral symmetry). The four sketches at the bottom are from conditions in which participants were told to create (a) any creature from an imaginary planet like Earth, (b) one with feathers, (c) one with fur, and (d) an imaginary creature with scales (Ward et al., 2002). Created ideas also tend to include properties generalized from known creatures with feathers (birds), fur (mammals), or scales (fish).

Blocker	Fragment	Solution
ANALOGY	A_L__GY	ALLERGY
BRIGADE	B_G_A_E	BAGGAGE
COTTAGE	C_TA__G	CATALOG
CHARTER	CHAR_T_	CHARITY
CLUSTER	C_U_TR_	COUNTRY
CRUMPET	CU_P__T	CULPRIT
DENSITY	D__NITY	DIGNITY
FIXTURE	F_I_URE	FAILURE
HOLSTER	H_ST_R_	HISTORY
TONIGHT	T_NG__T	TANGENT
TRILOGY	TR_G__Y	TRAGEDY
VOYAGER	VO__AGE	VOLTAGE

Fig 23.2 Word fragments, their correct solutions, and blocker words used to show an implicit memory blocking effect (Smith & Tindell, 1997).

blocking responses are put out of mind. In the case of incubation effects, many puzzles or insight problems initially may promote ideas or ways of thinking that are ultimately found to be inappropriate solutions—blockers—for those problems. The forgetting fixation hypothesis states that getting blockers out of mind can benefit creative problem solving. The same hypothesis explains reminiscence by focusing on *output interference* that occurs on the initial recall test; as items are recalled from a memory set, their subsequent probability of being retrieved again is increased. This results in a biased retrieval set in which initially recalled (and strengthened) items block recall of other items in the same memory set. The forgetting fixation hypothesis explains reminiscence as a decrease (after a time lag) in the blocking effect exerted by initially retrieved items in the same memory set, thereby allowing initially blocked items to be retrieved (e.g., Smith, 1995a).

Empirical tests of the forgetting fixation hypothesis in reminiscence and incubation show clear support for the hypothesis. Reminiscence, defined as recalling on a second test items not recalled on an earlier test, can be explained by the incremental hypothesis as the result of continued retrieval efforts, and since more attempts will eventually find initially unrecalled items, those items might be recalled on a second test (Roediger & Thorpe, 1978). What if a second (unexpected) recall test is given after a delay during which participants are kept busy? The incremental hypothesis predicts that reminiscence should drop if the retest is delayed because initially unretrieved items are even harder to retrieve after a delay. The forgetting fixation hypothesis, however, predicts that a delay permits

weakening of initial output interference, resulting in greater reminiscence on a delayed test. Smith and Vela (1991) showed *incubated reminiscence* effects, consistent with the forgetting fixation prediction: More initially unretrieved items were recalled if a retest was delayed.

A similar pattern of results has been found in creative problem solving, using puzzle problems (Smith & Blankenship, 1989) and Remote Associates Test problems (Kohn & Smith, 2009; Smith & Blankenship, 1991; Vul & Pashler, 2007) (see Fig 23.5). To ensure that initial fixation occurs, some participants in these studies were exposed to misleading hints before their first attempt at solving these problems, so initial fixation was experimentally introduced, and its effect verified by poorer initial performance relative to control group conditions. Retesting immediately versus after a delay yields consistent incubation effects; that is, problems not initially solved are more likely to be solved after a delay, as compared to immediate retesting conditions. Furthermore, these incubation effects are more robust when fixation is experimentally introduced. Thus, the forgetting fixation hypothesis, which explains reminiscence effects, also explains incubation effects in creative problem solving (Fig 23.6).

Incubation effects in tip-of-the-tongue (TOT) resolution have also been reported. When a name or word that could not be retrieved initially is later remembered, it often seems to happen in the absence of the initial TOT experience. Because TOT states have sometimes been attributed to momentary memory blocks (e.g., Jones, 1989; Jones & Langford, 1987; Reason & Lucas, 1983), these TOT recovery experiences may reflect the same underlying cognitive processes that give rise to incubation effects. Choi and Smith (2005) asked participants to name eight capital cities, each cued by the names of the country, eight names of diseases cued by disease descriptions, eight names of celebrities cued by their photographs, and so on, asking for graded TOT judgments whenever a name or word could not be remembered. Resolution of TOT states (i.e., successful recall of initially unrecalled items) was greater if retesting followed an incubation period than if retesting was not delayed, and this TOT incubation effect was greater for TOT states that had been judged stronger. It was assumed that some of these TOTs were caused by blocking because not one, but eight questions were given for each category, a procedure known to cause output interference (e.g., Brown & Hall, 1979). On the other hand, Kornell and Metcalfe (2006), who

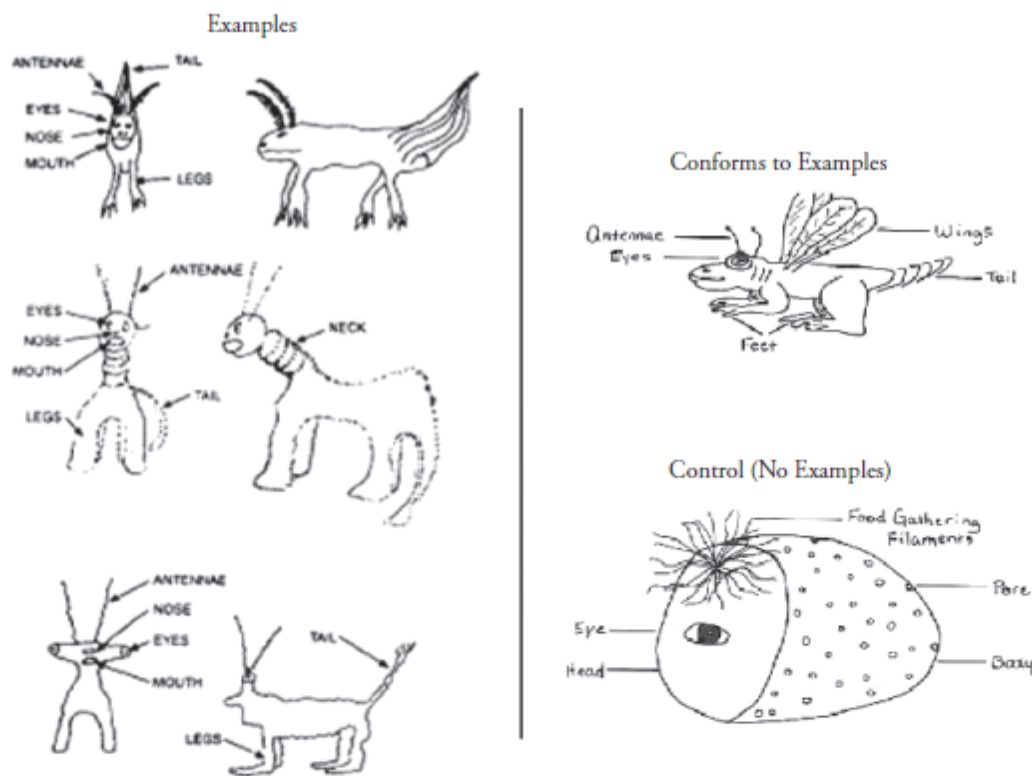


Fig. 23.3 The left panel shows examples seen by half the participants, who all tried to create life forms that might evolve on an imaginary planet similar to Earth. The top right shows an idea from a participant who saw the three examples; this sketch contains all three of the exemplified features (four legs, antennae, tail), a conformity effect that is found even when participants are asked to design ideas that are as different as possible from the examples. The bottom right shows an idea with none of those features, sketched by a participant who saw no examples (Smith et al., 1993).

also found incubation effects in TOT resolution, found that incubation did not interact with initial blocking self-reports, and reminding participants of their reported blockers at retest did not affect TOT resolution, casting doubt on the forgetting fixation hypothesis of TOT resolution. In that study, blocking was not directly manipulated but rather defined in terms of metacognitive reports of blocker experiences. Thus, whether incubated TOT resolution can be explained by forgetting blockers remains in question, probably due to the likelihood that TOTs have multiple causes, such as partial activation, memory blocking, and experiment demand characteristics.

Problem Solving

Creative and noncreative problem solving can be distinguished. Using known algorithms or heuristics to solve a problem, or simply retrieving a known solution from memory, would be considered noncreative problem solving, whereas creative problem solving involves solving new problems or solving old problems in new ways. Not all creative thinking can be described as creative problem solving, but much creative cognition research frames the activity that way.

One distinction that separates creative and noncreative problem solving is the concept of *well-defined*

versus *ill-defined problems*. A problem is considered well defined (and not creative) if its beginning state and goal state are thoroughly specified, in addition to the operations to be used in getting from the beginning to the goal (Reitman, 1965). Creative problems are considered ill defined, primarily because multiple hypothetical solutions might satisfy the goals of the problem. Another approach distinguishes *divergent* from *convergent problem solving*. Whereas a convergent problem has a single correct answer, divergent problems have many possible solutions (e.g., Finke, Ward, & Smith, 1992). Divergent problem solving will be discussed in the next section.

The topic of insight (e.g., Dominowski & Jenrick, 1972; see also van Steenburgh et al., Chapter 24) often has been studied as a type of creative problem solving. It is important to distinguish the concepts of insight, insight problems, and insight experiences. Whereas *insight* refers to a clear and/or deep understanding, *insight experiences* (also known as *aha!* experiences) are insights that are experienced suddenly and unpredictably. *Insight problems* are puzzle problems that are typically (but not necessarily) solved by insight experiences (Finke et al., 1992; Smith, 1995a). Insight problem solving, as discussed earlier, often has been described as accompanied by a perceptual-like restructuring of

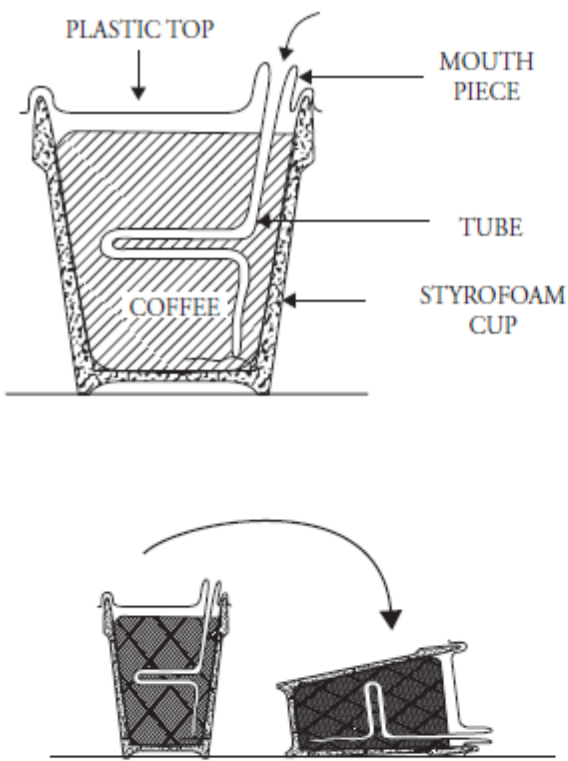


Fig. 23.4 Example spill-proof coffee cup given to some participants in Jansson and Smith (1991). Although the example uses a straw and a mouthpiece (which could lead to scalded mouths), these features were explicitly disallowed for designs sketched by participants. Nonetheless, design students who saw this example were far more likely to include straws and mouthpieces in the designs they sketched, as compared with students who did not see the example.

the problem, that is, discovering a new or different way to frame a problem in a manner similar to the way that an alternative interpretation of an ambiguous figure might be discovered (e.g., Dominowski, 1981; Duncker, 1945; Ellen, 1982; Maier, 1930; Metcalfe, 1986) (see Fig. 23.7). Initial attempts to solve insight problems often result in fixation, impediments caused by retrieval of inappropriate prepotent responses or methods. Recent research suggests that inhibition of prepotent responses may facilitate insight problem solving by providing a means by which to overcome fixation (Storm & Angello, 2010).

Implicit Cognition

Cognitive processes that occur without explicit awareness or deliberate intention can be described as *implicit cognition*. Implicit or unconscious cognition has long been considered to play a critically important role in the creative process. The idea that insights or solutions to problems can be arrived at via unconscious processes has been long endorsed as the reason that creative solutions seem to appear unbidden, and often occur outside of the typical problem-solving context, even when conscious work has been put aside. On the one hand, no evidence indicates that unconscious cognitive processes, like conscious processes, are capable autonomously of carrying out sequences of knowledge states, with each step using the products of previous states. On the other hand, there has been evidence that unconscious processes similar to spreading activation might be responsible for intuitive hunches (e.g., Bowers, Farvolden, & Mermigis, 1995), that impending solutions to insight problems cannot be predicted more in advance than about 10 seconds (Metcalfe, 1986), and that inventors and students in creative fields are often subject to involuntary conformity effects (e.g., Smith, Ward, & Schumacher, 1993).

The type of implicit cognition most often referred to in reference to creative thinking is spreading activation that occurs below the level of conscious awareness. Below-threshold activation has been the mechanism for a theory that implicit cognition can lead incrementally, but below the level of conscious awareness, toward an insight, and the final step in the process that completes an idea is simply the product of numerous incremental steps, not a cognitive restructuring (e.g., Weisberg, 1992). Yaniv and Meyer (1987) found that answers to general knowledge questions were responded to faster in a lexical decision task even if a participant could not consciously retrieve the answer, and furthermore, the stronger the feeling-of-knowing report accompanying the initial retrieval failure, the clearer the lexical decision advantage. They attributed this

Remote Associates Test Problems			Blockers	Solutions
SALAD	HEAD	GOOSE	lettuce	egg
BED	DUSTER	WEIGHT	room	feather
APPLE	HOUSE	FAMILY	green	tree
CAT	SLEEP	BOARD	black	walk
WATER	SKATE	CUBE	sugar	ice
ARM	COAL	STOP	rest	pit

Fig. 23.5 Remote Associates Test (RAT) problems, along with examples of blockers (related to two but not all three test words) and solutions (a single word related to each of the three test words).

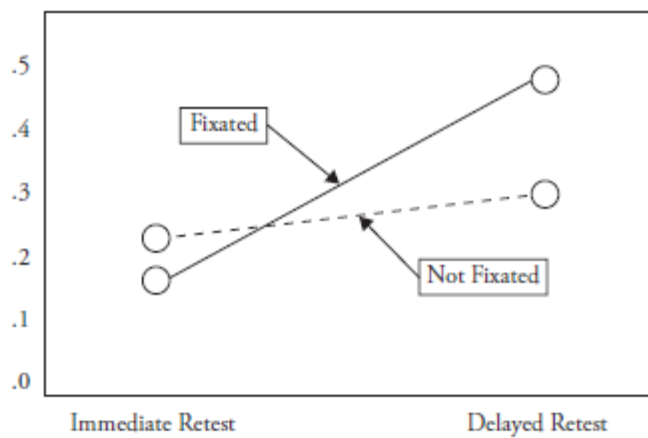


Fig. 23.6 Proportion of initially failed problems that were resolved on a retest that was given either immediately, or after a 5-minute delay. Problems with no misleading “hints” on the original test (Not Fixated) did not show an incubation effect (defined as better resolution on the delayed retest), but those with misleading hints (Fixated) showed a clear incubation effect (from Experiment 1 of Smith & Blankenship, 1991).

priming effect to below-threshold activation of target items, caused by the unsuccessful retrieval attempts. Although Connor, Balota, and Neely (1992) later challenged the interpretation of their results, Yaniv and Meyer claimed that such activation could be the mechanism underlying incubation effects. Seifert et al. (1994) expanded upon this idea, arguing that “failure indices” may become attached to initially unsuccessful retrieval attempts, and chance encounters with related stimuli are more likely to trigger insights or *aha!* experiences. This “opportunistic assimilation” theory, based on unconscious activation of concepts, has been offered as a theory of incubation effects.

Another feature of creative thinking, *intuition*, has been treated as below-threshold activation by Bowers and colleagues (Bowers et al., 1990, 1995). In contrast with insight, an idea one becomes consciously aware of, intuition is treated as a “hunch” by Bowers and colleagues. According to this view, intuitive guiding, rising from unconscious activation, can lead one toward more coherent solutions. A similar aspect of implicit cognition has been examined in terms of predicting insight experiences in problem solving (Metcalf, 1986; Metcalf & Weibe, 1987). These studies introduced a metacognitive definition of insight experiences, based on repeated subjective reports known as *warmth ratings*. Because intuition is defined as a hunch, or an ineffable “gut feeling,” warmth ratings might be considered estimates of intuition. For noninsight problems, this metacognitive measure shows regular increases over time until a solution is reached. For insight problems, however, increasing warmth ratings did not predict impending solutions; rather, they predicted impending failures. Metcalf’s research shows that intuition may not be a good predictor of insight.

Implicit memory in the form of involuntary retrieval of recently encountered stimuli has been

linked to fixation and conformity effects in creative invention and problem solving (e.g., Smith, 1995b, 2003). Smith and Tindell (1997) used word fragment completion to induce implicit memory blocks, priming with words orthographically similar to test fragments, but that could not correctly complete the fragments. The resulting implicit memory blocks (e.g., Kinoshita & Towgood, 2001; Leynes, Rass, & Landau, 2008; Logan & Balota, 2003; Lustig & Hasher, 2001) are not eliminated when participants are explicitly warned not to think about read words while they were completing the test fragments. Parallel results have been reported, showing that similar warnings do not mitigate conformity effects in creative idea generation (Smith et al., 1993) or fixation in creative design (Jansson & Smith, 1991).

Creative Operations, Procedures, and Activities

Although no fixed set of cognitive operations or procedures is common for all creative activities, there are, nonetheless, some that often are encountered and considered in the research literature on creative thinking. These operations include the practice of generating lists of ideas (also known as idea generation, or ideation) and combining ideas.

Combination

One of the challenges people confront as a result of relying heavily on existing knowledge in performing creative tasks is generating something new, something that goes beyond what is already known. Indeed, this requirement also represents a challenge for researchers attempting to explain creativity. How are we to account for the appearance of something new if all people have to work with is their existing knowledge? One process that can help with both challenges is *conceptual combination*, in which people merge together two concepts that were previously

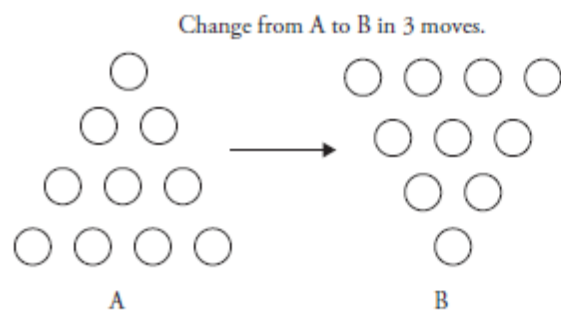


Fig. 23.7 An insight problem, one whose solution tends to be realized suddenly (e.g., Metcalfe, 1986).

completely separate or are otherwise discrepant or dissimilar (e.g., Medin & Shoben, 1988; Shoben & Gagne, 1997; Sifonis & Ward, 1998; Wisniewski, 1997). One of the reasons conceptual combination can be effective in provoking or explaining the origins of novelty is that it can result in the emergence of properties that are not strongly associated with either of the parent concepts in the combination. The creative potential inherent in those *emergent properties* can then serve as the basis for a new ideas or products. A classic example of emergence is seen in the interpretation of the somewhat unusual combination “Harvard-educated carpenter,” which might be perceived as being nonmaterialistic, a property not necessarily strongly associated with Harvard-educated people or carpenters in general (e.g., Kunda, Miller, & Claire, 1990). Research is consistent with the idea that the more discrepant the separate concepts are, the more likely it is that emergent properties will be observed (e.g., Estes & Ward, 2002; Hampton, 1987; Wilkenfeld & Ward, 2001), possibly because discrepancy forces people to attempt to resolve the contradiction between the component terms (Hampton, 1997; Kunda et al., 1990).

Ideation

Divergent thinking, the search for many varied and imaginative possible problem solutions, has been contrasted with *convergent thinking*, a type of problem solving or reasoning in which cognitive operations are intended to converge upon the single correct answer to a problem. In divergent thinking tasks, people begin with an ill-defined or open-ended problem, such as finding alternative uses for a common object (e.g., Finke et al., 1992). Performing a divergent thinking task resembles the task of listing members of categories; in both cases, the subject brings all of the required knowledge to the task. There is a tendency to think of these two activities as fundamentally different. Whereas responses in category

generation tasks are often seen as passively residing in a memory repository, ideas for an idea generation task seem to be created on the spot. However, both of these assumptions are flawed. Most categories (e.g., *birds*) have a graded structure, with some members perceived as better members (e.g., *robin*) and others as poorer (e.g., *phoenix*), and ad hoc categories (e.g., *heavy things*), in particular, clearly demand on-the-spot imagination (e.g., *a sumo wrestler's lunchbox*; see Barsalou, 1982, 1985). Divergent thinking, like category generation, requires both retrieval of material from memory and imagination.

When done as a collaborative group, ideation is usually referred to as *brainstorming* (e.g., Osborn, 1957). There are other collaborative methods intended to enhance ideation, but generating and combining ideas is the basic goal of such activities.

Creative Cognition Theories

It is not easy to demarcate theories of creative cognition from theories of cognition. For example, Gentner's structural mapping theory (e.g., Gentner, 1987; Gentner & Markman, 1994; see Holyoak, Chapter 13) deals with analogical reasoning and is relevant to important issues in creative cognition, yet we would not call it a creative cognition theory; rather, it is a theory of cognition that we use to describe aspects of creative thinking. In comparison, Ward's (1994) structured imagination theory was specifically designed to address certain aspects of creative thinking, and it is couched in terms of cognitive theory; therefore, it qualifies as a theory of creative cognition. Here we briefly review theories that were intended to capture important aspects of creative cognition.

Remote Association

The theory of *remote association* (e.g., Mednick, 1962; Mednick, Mednick, & Mednick, 1964), inspired by studies of associative responses given by schizophrenic patients (e.g., Mednick, 1962), took a narrow view of creative thinking as a single associative process. The idea is that the process of accessing or retrieving a remote associate of a stimulus, rather than a common or prepotent response, is a cognitive event at the heart of all truly creative thinking. This process, accessing a remote association, should be useful in the tricky sort of creative problem solving in which the prepotent (“sucker”) initial response implicitly includes unnoticed assumptions that prevent successful problem solving. The ability to access a more remote association allows the creative problem solver to go beyond the initial fixation

caused by the prepotent response. Furthermore, remote access allows a person to combine more distantly related ideas or concepts; such unusual combinations might produce novel emergent properties, a hallmark of many creative ideas.

Martindale (1981, 1989, 1995) elaborated and extended the theory of remote association, adding mechanisms such as attentional defocusing (or narrowing) that can impact the gradient of associative hierarchies. A steep associative hierarchical gradient (where prepotent responses are far more likely than other associates to be accessed) can shift to a flatter gradient, in which remote associates are more accessible (Martindale, 1995). Flattening of this associative gradient via defocused attention, according to Martindale, should be directly related to sympathetic arousal levels, because lower arousal acts to increase the randomness (temperature) function in Martindale's connectionist model, facilitating escape from local minima.

Darwinian Model

A Darwinian model of creativity is one that embraces the notion of random variation and selection at the level of ideas (e.g., Simonton, 1999; see Simonton, Chapter 25). That is, one must continue to produce variations of ideas until, by chance, an idea turns out to be creative and valuable. Key to this theory is the idea that creativity is a stochastic process, rather than a deterministic one. That is, one cannot produce creative products by virtue of a preplanned step-by-step process. Rather, creativity is seen as a lucky accident. Therefore, increasing the chances of a providential accident can be accomplished by increasing the number of ideas that are generated and considered in the course of creative ideation.

This Darwinian theory of creative ideation does not really specify the cognitive mechanisms that determine variations in the quantity of ideas that can be generated and, in fact, does not depend upon the empirical validity of any cognitive mechanisms, except for those that might contribute to the quantity of ideas that are produced. Indeed, the quantity of ideas, often measured as fluency, is one of the most common measures of creative productivity. Most experimental studies of brainstorming, for example, have relied upon measures of the quantity of ideas produced in various conditions. Shah et al. (2003) referred to quantity as a *process* measure, rather than an *outcome* measure of creativity. That is, more ideas might increase the chances that a highly creative

idea will be produced (the Darwinian principle), but quantity is not a necessary outcome if someone only thinks of that single most creative idea.

Opportunistic Assimilation

The "prepared mind" theory, based on Pasteur's notion that "Chance favors the prepared mind," is another cognitive model of aspects of creative thinking. Encompassing the principle of the prepared mind is the *opportunistic assimilation* theory of Seifert and colleagues (e.g., Patalano & Seifert, 1997; Seifert et al., 1994; Seifert & Patalano, 2001). This theory explains insight experiences with a combination of several cognitive mechanisms, including (unconscious) spreading activation, failure indices encoded with unsolved problems, and serendipitous environmental triggers. The theory states that recognizing opportunities to fulfill pending goals is improved by predictively encoding one's goal, which allows people to take advantage of unforeseen opportunities to achieve those goals. When attempts to solve a problem result in initial failures, these episodes can be encoded in memory as associations between pending goals and stimulus features that might potentially solve the failed problem. Unsolved problems that are encoded in association with these "failure indices" may be remembered when stimuli with features related to those indices are serendipitously encountered. Furthermore, unconscious semantic activation of failed problems primes the encoded representations of unsolved problems, making them more likely to be remembered when such chance encounters occur (e.g., Yaniv & Meyer, 1987).

According to the opportunistic assimilation theory, this combination of encoded failure indices and unconscious spreading activation describes the prepared mind, because it prepares the problem solver to be able to use relevant cues without requiring the examination of every object in the environment to consider its relevance to the unsolved problem. Encoding more abstract versions of failure indices, according to this view, is more advantageous than specific or concrete encodings because abstract problem needs might be satisfied by an entire class of objects, rather than requiring a specific object. This opportunistic assimilation was designed to explain incubation effects in creative problem solving: When one initially fails to solve a problem, and the problem is put aside, a serendipitously encountered object in one's environment can provide a relevant clue, triggering an insight.

Idea Roadmaps

Smith's roadmaps theory (Smith, 1995a) provides a theoretical basis for a generative search of one's knowledge, a search for information that could potentially address one's goals and problem solutions. The theory does not assume that goals or problem solutions are necessarily stored in their final form, but rather that goals are achieved via an incremental construction process that can combine preexisting knowledge with new ideas constructed from combinations of existing knowledge. The theory can be applied to creative problem solving, design, or other similar constructive activities.

The multidimensional space in which ideas are constructed, according to an extension of this theory (Smith, 1995b), is determined and bounded by the *plan* adopted to guide thinking. This type of plan includes a set of operations for manipulating the content of ideas that are under construction; these operations, combined with the content that serves as a problem's initial representation, determine an idea space that can be constructed and navigated as the idea is developed. If this idea space is arranged hierarchically, with each location defined in terms of the idea's specified content, then this idea roadmap can be oriented with the least specific content at the top of the roadmap and the most specified ideas at the bottom of the hierarchy. Typical problem solving, according to this theory, tends to begin at or near the top of a roadmap and proceed incrementally toward the bottom of the roadmap, where specific solutions are represented. During creative idea construction, each successive representation of an idea on a roadmap tends to be a precursor for a more specific representation, so there may be a tendency to include each represented set of elements automatically on subsequent problem-solving steps. Thus, representations on the roadmap of ideas tend to encode implicit knowledge, memories, or assumptions about problem solutions.

Fixation, according to this theory, corresponds to taking a dead-end branch in the path that is constructed in the course of creative problem solving. If a problem solution or a creative insight is not located on a projected idea map, and we assume only downward movement within the idea space, this provides a way to view fixation in creative thinking. "Upward" movement on an idea roadmap involves *removing* elements from idea representations, which can be especially difficult for elements that have become implicitly included components of a representation. Incubation, in this theory, allows one

to escape from dead-end fixated paths. If a break or context shift enables a new idea representation that does not include fixating elements, then fixation may be resolved—an incubation effect, due to restructuring of the problem.

This roadmaps theory blends well with Ward's ideas about structured imagination and his path-of-least-resistance theory, as described earlier. That is, a hierarchically structured conceptual map forms the basis of imagination in both cases. In the structured imagination view, beginning ideation with a representation that is too concretely specified can limit the breadth of one's search for ideas. In the roadmaps view, fixation and conformity due to recent experience can likewise limit the breadth of idea generation.

Metrics of Creativity

How can we recognize creativity when we see it? How can we measure creativity? The same basic questions have been asked about other cognitive domains, such as memory. Cued recall and word stem completion are two different measures commonly used to measure memory; which is a better measure of the construct? Most cognitive psychologists understand the absurdity of this question, because the answer begins with "It depends on what you want to measure." There is no "single" or "best" measure of memory, because memory involves many complex interacting systems. The same can be said about creativity. What is the best measure of creativity? It depends on what aspect of creative thinking you want to measure. Studies of creative thinking often focus on specific aspects of creative cognition, such as creative problem solving, idea generation, conceptual combination, or visualization.

Although many studies have looked at performance on insight problems to measure creative problem solving (e.g., Maier, 1931; Metcalfe, 1986; Smith & Blankenship, 1989, 1991), studies of creative thinking must go beyond puzzles to connect cognition with creative products. In these cases, the most typical metrics used to measure creative output are the *quantity*, *quality*, *variety*, and *novelty* of responses or products. For example, in a divergent thinking task in which one is asked to list the alternative uses of empty 2-liter soda bottles, the number of ideas listed is the quantity, the number of categories of ideas (e.g., construction, weapon, things that float) is the variety, and the statistical infrequency of each idea, as measured by a norm, is the novelty. Quality is usually subjectively judged. Shah et al. (2000) distinguished *process metrics* from

outcome metrics of creative ideation, stating that the novelty and quality are important for judging the outcome or end product of creative work, whereas quantity and variety are important only for judging aspects of the creative process. These four metrics, and variants of them, have proven useful in different ideation contexts, such as divergent thinking tasks (e.g., Guilford, 1967), brainstorming (e.g., Kohn & Smith, 2010), and engineering design (e.g., Vargas-Hernandez, Shah, & Smith, 2010). Nonetheless, there are important limitations of these creativity metrics. One limitation has to do with domain differences and idiosyncrasies (e.g., engineering design may have many important creative needs that differ from those of music composition, business, and science).

Some relatively new metrics of creative cognition have been identified, including measures of conformity, emergence, and abstraction. Smith et al. (1993) defined *conformity* as using features of examples one has seen in one's own creative ideas. They and others (e.g., Dahl & Moreau, 2002; Jansson & Smith, 1991; Vargas-Hernandez et al., 2010) have shown that conformity may not be overcome by instructions to avoid using features of examples. Kohn and Smith (2010) showed that brainstorming participants tend to conform to the ideas of others in their brainstorming group. Although the term "conformity" typically is used pejoratively, it is clearly the case that conforming to useful examples in education and training is quite useful and important. When examples block or unnecessarily limit creative thinking, however, conformity is a problem. *Emergence* has been measured as a property seen in creative thinking in which combinations of ideas can produce concepts with qualities that are not seen in the component concepts (e.g., Estes & Ward, 2002; Wilkenfeld & Ward, 2001), and it has been used as a measure of creative cognition (e.g., Kerne, Smith, Koh, Choi, & Graeber, 2008a). Another metric of creative thinking is *abstraction*, that is, progressing from relatively concrete representations to more general levels, which potentially enables a broader variety of ideas. Abstraction can circumvent fixation and overly structured imagination (e.g., Ward et al., 2004), and it may promote access to remote associations and analogies.

Impediments and Aids to Creative Thinking

There are several known impediments and aids to creative thinking that relate directly to patterns

of cognition. Here, we briefly review some of these impediments and aids.

Impediments

INADEQUATE KNOWLEDGE

Perhaps the most common impediment to creative thinking is a lack of knowledge and resources (e.g., Weisberg, 1992, 2006). Both everyday creativity and extraordinary creativity (see Simonton, Chapter 25) require prior knowledge and experience. A myth of creativity is that one needs no expertise, and that an active imagination is all one needs to create great things; such notions are nonsense. A creative imagination is necessarily structured according to one's prior knowledge (e.g., Ward, 1994), and the value of serendipitous discoveries can only be noticed or realized by those with some level of expertise in a domain.

IMPLICIT ASSUMPTIONS

Although knowledge and experience are necessary for creative thinking, they are not sufficient in many identifiable cases. Inappropriate ideas or approaches to a problem can impede creative thinking via fixation (e.g., Smith & Blankenship, 1989, 1991; Wiley, 1998) and the implicit use of inappropriate assumptions (e.g., Smith, 1994). Findings that show fixation and implicit assumptions (e.g., Luchins & Luchins, 1959) can block creative cognition and demonstrate that prior experience can, at times, have negative consequences (see Fig 23.8). What is insidious about the implicit assumptions that can cause fixation is that such impediments are hidden from one's conscious mind, making them difficult to detect and remedy.

COGNITIVE ILLUSIONS

Cognitive illusions, such as false memories (e.g., Roediger & McDermott, 1995), memory misattributions (e.g., Jacoby, 1991), or misapplied availability heuristics (e.g., Tversky & Kahneman, 1974), cause predictable, systematic cognitive errors. One cognitive illusion that can impede creative thinking is *hindsight bias*. The sense that retrospective views of ideas make them seem more obvious can impede certain aspects of creativity (e.g., Fischhoff, 1975). A good example of hindsight bias can be seen in the patent process. A U.S. patent can be granted only for inventions that are "nonobvious" to practitioners of a profession. This nonobviousness criterion may lead to denial of patents for creative ideas that, in retrospect, might seem obvious to patent examiners (e.g., Seifert, 2008; Smith, 2008).

Problem #	Jar A	Jar B	Jar C	Goal Amount	Solution
1	64	100	6	24	B - A - 2C
2	21	73	5	42	
3	6	28	7	8	
4	35	94	21	17	
5	22	49	12	3	
6	7	56	8	33	
7	15	39	3	18	
8	28	76	3	25	

Fig. 23.8 Luchins' water jar problem: Using only the jars A, B, and C as measuring devices, measure out the desired amount for each problem. The mental set $B - A - 2C$, learned early in the problem sequence, may become mindlessly reapplied on each successive problem. This fixation effect, that is, blind use of a mental set, leads to use of a complicated solution ($B - A - 2C$) where a simple one should be apparent on Problem 7 ($A + C$), and it leads to the use of an incorrect solution ($B - A - 2C$) on Problem 8, even though a simple correct solution ($A - C$) should be readily apparent.

PREMATURE CONCEPTUALIZATION

One may begin creative work on an idea with a relatively specific or concrete representation, or one may reach such a representation early on in the process. Taking the path of least resistance, one may thereafter implicitly include all of those prematurely specified features in subsequently developed versions of a creative idea, never considering ideas that lack those features.

Aids

Creativity can be aided in many ways, such as gaining knowledge and expertise, using analogies, combining ideas, thinking abstractly, redefining problems that are fixated, and noticing ways in which a new idea could have important implications.

COMBINATION

Ever since people have tried to encourage creative thinking, the notion has flourished that combinations of existing ideas can form the basis of creative ideas (e.g., Osborn, 1957). As more interpretations of a conceptual combination are generated, the interpretations increase in their normative originality, and they tend to be based more on idiosyncratic knowledge of the components of the combination. One of the main goals in creative conceptual combination is to discover new and potentially useful emergent properties: that is, properties not commonly seen in the component concepts, but that emerge only in combinations (e.g., Estes & Ward, 2002).

ANALOGY

Because analogies link conceptual domains that are similar, they can provide vehicles for constructing creative solutions that cannot be found within the domain of a problem (e.g., Gick & Holyoak, 1980; see Holyoak, Chapter 13). Typically, the most useful analogies will be those that are based on the similarity of deeper meaningful levels of problem topics and solution vehicles, as opposed to similarity of superficial features of topic and vehicle domains. Local analogies are those that are conceptually closer to a problem topic domain than are remote analogies. Like remote associations, remote analogies appear to be more useful than local analogies for creative design (e.g., Christensen & Schunn, 2007), whereas Dunbar (e.g., 1997) found the reverse for a group of scientists engaged in scientific problem solving (also see Dunbar & Klahr, Chapter 35).

ABSTRACTION

Because imagination is structured according to underlying concepts in memory (e.g., Ward, 1994), beginning creative idea development at a convenient basic level and then taking the path of least resistance can lead to premature conceptualization. Abstract thinking, particularly early on in the ideation process, can lead one to explore a greater range of ideas, effectively expanding the conceptual space under consideration.

NOTICING

Stumbling across a key clue is not sufficient; one must *notice* the implications of that clue and realize its implications in terms of creative products or unsolved problems. No mind can be prepared to notice such clues without sufficient expert knowledge. Noticing may be facilitated by frustration from initial failures, which potentiates unsolved problems, helping them come to mind when relevant clues appear (e.g., Patalano & Seifert, 1997; Seifert et al., 1994).

KNOWLEDGE

Ideally, an expert always knows the correct approach for any given problem. Even experts, however, are susceptible to fixation and conformity effects in inventive design tasks (e.g., Jansson & Smith, 1991; Linsey et al., 2009). Redefinition of a problem or goal can sometimes provide a key insight, a restructuring of the problem, particularly when problems cannot be solved using expert

heuristics. One way to aid redefinition is via perspective shifts: thinking about problems in new contexts, ones that may not be associated with fixated approaches. Another aid to redefinition is analogy (e.g., Linsey, Wood, & Markman, 2008).

SUPPORT TECHNOLOGIES

Although there are many physical tools and technologies that aid the cognitive structures and operations that give rise to creativity, sketching is one of the oldest and most universal of these external aids (see Hegarty & Stull, Chapter 31). Sketching provides a particularly good medium for expressing and sharing spaces, schemas, and mental models (Tversky & Hard, 2001), freeing up cognitive resources, and extending our visualization abilities in ways that are particularly conducive to creative cognition (Tversky, 2001, 2005). Because sketches can be reexamined and reconsidered, they can support restructuring and discovery of unanticipated relations (Goel, 1995; Goldschmidt, 1994; Suwa & Tversky, 2001; Tversky & Suwa, 2009).

Conclusions

Creative thinking involves all of the cognitive systems. There is no single creative process; rather, there are many different types of creative ideas, and many ways in which ideas can be generated, constructed, and developed. Many of these pathways to creativity can be described and explained in terms of the cognition that underlies the creation of ideas. As in most other areas of cognitive psychology, the creative cognition approach has used empirical science to study the nature and functioning of cognitive processes and structures that underlie creative thinking. Cognitive operations that often are involved in creative cognition include divergent idea generation, the formation of conceptual combinations, retrieval and mapping of analogies, abstraction, visualization, and conceptual restructuring. Common impediments to creative cognition include inadequate prior knowledge, implicit assumptions, cognitive illusions, and premature conceptualization in the development of creative ideas. Methods and tools that can support creative cognition must be based on the cognitive operations and structures that give rise to creative ideas.

Future Directions

Cognitive Neuroscience

The role of the brain and nervous system in creative cognition is beginning to be explored by some

cognitive neuroscientists, and there are many ways in which neuroscientific mechanisms might contribute to creative thinking. Martindale, for example, linked access to remote associates with the effects that low physiological arousal have on neural communication (e.g., Martindale, 1981, 1995). Another excellent example is the work of Jung-Beeman, Kounios, and others who have developed a theory of insight and comprehension based on functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) studies of participants solving insight problems (e.g., Jung-Beeman, 2005; Jung-Beeman et al., 2004; Kounios et al., 2006; Kounios et al., 2008). These studies have found, for example, activity in the right anterior superior temporal gyrus linked with awareness of a solution to an insight problem (e.g., Jung-Beeman et al., 2004; see van Steenburgh et al., Chapter 24). Future research on the neuroscience of creative cognition must blend neuroscience with cognitive mechanisms that are well known for their link to creative thinking, as the aforementioned studies have already begun to do.

Collaborative Cognition

Much of the cognition involved in real-world creativity is done collaboratively, using multiple types of media. Many studies have documented brainstorming deficits when participants are in groups: More ideas are produced when the individuals brainstorm individually (e.g., Diehl & Stroebe, 1987, 1991; Kohn & Smith, 2010; Nijstad et al., 2003; Nijstad & Stroebe, 2006). Cognitive mechanisms such as fixation and conformity to the ideas of others have been shown to limit the number and the novelty of ideas of brainstorming participants (Kohn & Smith, 2010). Parallel findings of collaborative inhibition in memory recall show that more is recalled when participants recall events individually (e.g., Weldon & Bellinger, 1997). Future research must pursue questions about the cognition that occurs in groups and how that cognition affects creativity. Particularly relevant to questions about collaborative creativity is the increasing role of the Internet in customer-driven design, and virtual teams (e.g., Maher, 2010; Ward, Guerdat, & Roskos, 2010).

Digital Tools

Digital tools that can aid creativity can be considered extensions of the types of human cognition that participate in creative cognition (Smith, Kerne, Koh, & Shah, 2009) (see Fig. 23.9). These digital tools can promote, for example, analogical

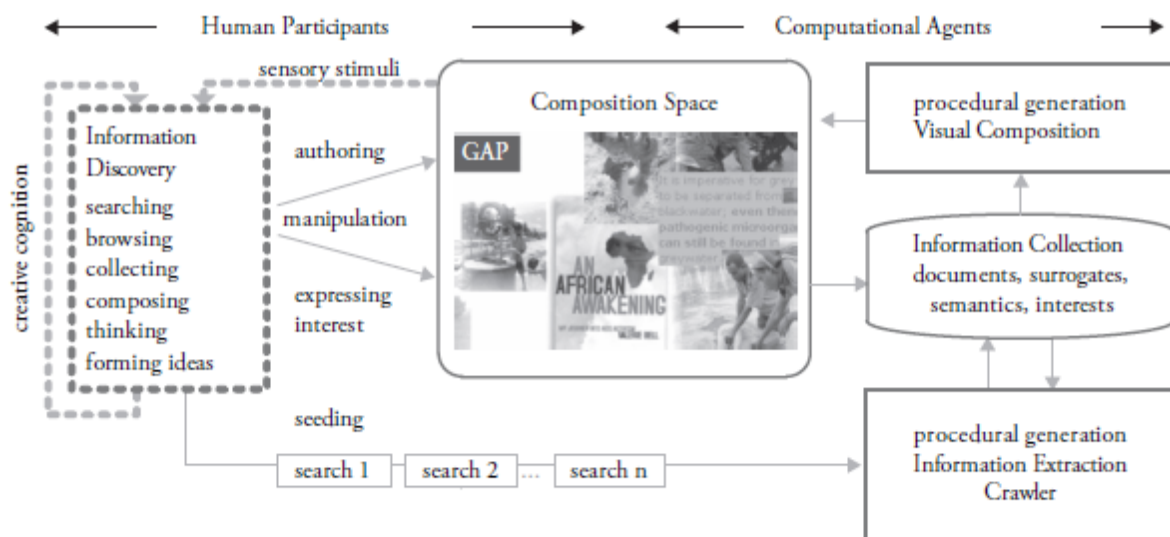


Fig. 23.9 Computational agents support human participants in the combinForm digital tool for information discovery, which involves browsing through collections returned by search engines and forming navigable compositions of relevant results (Kerne, Koh, Smith, Webb, & Dworaczky, 2008b). Problems are iteratively reformulated, representations are manipulated, and solutions constructed, often involving integration of multiple information resources (Kerne & Smith, 2004). See color figure.

reasoning (Markman, Wood, Linsey, Murphy, & Laux, 2009), conceptual combination of remote associates (Kerne et al, 2008a), or abstract thinking (Ward, 2009). Future research in creative cognition should examine this fundamental link between cognition and digital tools designed to support and enhance creativity.

Creative Expertise

Do some people gain creative expertise; that is, do they become expert at recognizing blocks, do they know good methods for escaping blocks, redefining problems, combining and transforming concepts, drawing deeply appropriate but remote analogies, and so on? Is this type of creative expertise something that can be effectively learned and trained? Whether such putative expertise actually enhances creativity is an important question for future research in creative cognition.

References

Barsalou, L.W. (1982). Context-independent and context-dependent information in concepts. *Memory and Cognition*, 10, 82–93.

Barsalou, L. W. (1985). Ideals, central tendency, and frequency of instantiation. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 11, 629–654.

Beghetto, R., & Kaufman, J. (2007). Toward a broader conception of creativity: A case for ‘mini-c’ creativity. *Psychology of Aesthetics, Creativity, and the Arts*, 1, 73–79.

Bower, G. H., Clark, M., Winzenz, D., & Lesgold, A. (1969). Hierarchical retrieval schemes in recall of categorized word lists. *Journal of Verbal Learning and Verbal Behavior*, 8, 323–343.

Bowers, K. S., Farvolden, P., & Mermigis, L. (1995). Intuitive antecedents of insight. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The creative cognition approach*. (pp. 27–51). Cambridge, MA: MIT Press.

Bredart, S., Ward, T. B., & Marczewski, P. (1998). Structured imagination of novel creatures’ faces. *American Journal of Psychology*, 111, 607–725.

Brown, A. S., & Hall, L. A. (1979). Part-list cuing inhibition in semantic memory structures. *American Journal of Psychology*, 92, 351–362.

Choi, H., & Smith, S. M. (2005). Incubation and the resolution of Tip-of-the-tongue states. *The Journal of General Psychology*, 132(4), 365–376.

Christensen, B. T., & Schunn, C. D. (2007). The relationship between analogical distance to analogical function and pre-inventive structure: The case of engineering design. *Memory and Cognition*, 35, 29–38.

Chrysikou, E. G., & Weisberg, R. W. (2005). Following the wrong footsteps: Fixation effects of pictorial examples in a design problem-solving task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 31(5), 1134–1148.

Connor, L. T., Balota, D. A., & Neely, J. H. (1992). On the relation between feeling of knowing and lexical decision: Persistent subthreshold or topic familiarity? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18(3), 544–554.

Dahl, D. W., & Moreau, P. (2002). The influence and value of analogical thinking during new product ideation. *Journal of Marketing Research*, 39, 47–60.

Diehl, M., & Stroebe, W. (1987). Productivity loss in brainstorming groups: Toward the solution of a riddle. *Journal of Personality and Social Psychology*, 53(3), 497–509.

Diehl, M., & Stroebe, W. (1991). Productivity loss in idea-generating groups: Tracking down the blocking effect. *Journal of Personality and Social Psychology*, 61(3), 392–403.

Dominowski, R. L. (1981). Comment on “An examination of the alleged role of ‘fixation’ in the solution of ‘insight’ problems.” *Journal of Experimental Psychology: General*, 110, 199–203.

- Dominowski, R. L., & Jenrick, R. (1972). Effects of hints and interpolated activity on solution of an insight problem. *Psychonomic Science*, 26(6), 335–338.
- Dunbar, K. (1997). How scientists think: On-line creativity and conceptual change in science. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 461–493). Washington, DC: American Psychological Association.
- Dunker, K. (1945). On problem solving. *Psychological Monographs*, 58, (5, Whole No. 270).
- Ellen, P. (1982). Direction, past experience, and hints in creative problem solving: Reply to Weisberg and Alba. *Journal of Experimental Psychology: General*, 111, 316–313.
- Erdelyi, M. H., & Becker, J. (1974). Hypernesia for pictures: Incremental memory for pictures but not words in multiple recall trials. *Cognitive Psychology*, 6(1), 159–171.
- Estes, Z., & Ward, T. B. (2002). The emergence of novel attributes in concept modification. *Creativity Research Journal*, 14, 149–156.
- Finke, R., Ward, T., & Smith, S. M. (1992). *Creative cognition*. Cambridge, MA: MIT Press.
- Fischhoff, B. (1975). Hindsight foresight: The effect of outcome knowledge on judgment under uncertainty. *Journal of Experimental Psychology: Human Perception and Performance*, 1, 288–299.
- Gelman, S. A. (1988). The development of induction within natural kind and artifact categories. *Cognitive Psychology*, 20, 65–95.
- Gentner, D. (1987). Structure mapping: A theoretical framework for analogy. *Cognitive Science*, 7, 155–170.
- Gentner, D., & Markman, A. B. (1994). Structural alignment in comparison: No difference without similarity. *Psychological Science*, 5, 152–158.
- Gick, M. L. & Holyoak, K. L. (1980). Analogical problem solving. *Cognitive Psychology*, 15, 306–355.
- Glucksberg, S., & Weisberg, R. W. (1966). Verbal behavior and problem solving: Some effects of labelling in a functional fixedness problem. *Journal of Experimental Psychology*, 71, 659–664.
- Goel, V. (1995). *Sketches of thought*. Cambridge, MA: MIT Press.
- Goldschmidt, G. (1994). On visual design thinking: The vis kids of architecture. *Design Studies*, 15(2), 158–174.
- Guilford, J. P. (1967). *The nature of human intelligence*. New York: McGraw-Hill.
- Hampton, J. A. (1987). Inheritance of attributes in natural concept conjunctions. *Memory and Cognition*, 15, 55–71.
- Hampton, J. A. (1997). Emergent attributes in combined concepts. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 83–110). Washington, DC: APA Books.
- Heit, E. (2000). Properties of inductive reasoning. *Psychonomic Bulletin and Review*, 7, 569–592.
- Jacoby, L. L. (1991). A process dissociation framework: Separating automatic from intentional uses of memory. *Journal of Memory and Language*, 30, 513–541.
- Jansson, D. G., & Smith, S. M. (1991). Design fixation. *Design Studies*, 12(1), 3–11.
- Jones, G. V. (1989). Back to Woodworth: Role of interlopers in the tip of the tongue phenomenon. *Memory and Cognition*, 17, 69–76.
- Jones, G. V., & Langford, S. (1987). Phonological blocking in the tip of the tongue state. *Cognition*, 26, 115–122.
- Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Sciences*, 9, 512–518.
- Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., & Greenblatt, R. (2004). Neural activity when people solve verbal problems with insight. *PLoS Biology*, 2, 500–510.
- Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The Four C model of creativity. *Review of General Psychology*, 13, 1–12.
- Kerne, A., Smith, S. M., Koh, E., Choi, H., & Graeber, R. (2008a). An experimental method for measuring the emergence of new ideas in information discovery. *International Journal of Human-Computer Interaction*, 24(5), 460–477.
- Kerne, A., Koh, E., Smith, S. M., Webb, A., & Dworaczek, B. (2008b). combinFormation: Mixed-initiative composition of image and text surrogates promotes information discovery. *ACM Transactions on Information Systems (TOIS)*, 27(1), 1–45.
- Kinoshita, S., & Towgood, K. (2001). Effects of dividing attention on the memory-block effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 27, 889–895.
- Kohn, N. W., & Smith, S. M. (2009). Partly versus completely out of your mind: Effects of incubation and distraction on resolving fixation. *Journal of Creative Behavior*, 43(2), 102–118.
- Kohn, N. W., & Smith, S. M. (2010). Collaborative fixation: Effects of others' ideas on brainstorming. *Applied Cognitive Psychology*, 24, 1–22.
- Kornell, N., & Metcalfe, J. (2006). "Blockers" do not block recall during tip-of-the-tongue states. *Metacognition Learning*, 1, 248–261.
- Kounios, J., Fleck, J. L., Green, D. L., Payne, L., Stevenson, J. L., Bowden, M., & Jung-Beeman, M. (2008). The origins of insight in resting state brain activity. *Neuropsychologia*, 46, 281–291.
- Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. L., Subramaniam, K., Parrish, T. B., & Jung-Beeman, M. J. (2006). The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science*, 17, 882–890.
- Kunda, Z., Miller, D. T., & Claire, T. (1990). Combining social concepts: The role of causal reasoning. *Cognitive Science*, 14, 551–577.
- Landau, J. D., & Lehr, D. P. (2004). Conformity to experimenter-provided examples: Will people use an unusual feature? *Journal of Creative Behavior*, 38(3), 180–191.
- Leynes, P. A., Rass, O., & Landau, J. D. (2008). Eliminating the memory blocking effect. *Memory*, 16(8), 852–872.
- Linsey, J., Tseng, I., Fu, K., Cagan, J., & Wood, K. (2009, August). *Reducing and perceiving design fixation: Initial results from a NSF-sponsored workshop*. Paper presented at the International Conference on Engineering Design, Stanford, CA.
- Linsey, J., Wood, K., & Markman, A. (2008, August). *Increasing innovation: Presentation and evaluation of the word tree design-by-analogy method*. Paper presented at the ASME IDETC Design Theory and Methodology Conference, New York, NY.
- Logan, J. M., & Balota, D. A. (2003). Conscious and unconscious lexical retrieval blocking in younger and older adults. *Psychology and Aging*, 18, 537–550.
- Luchins, A., & Luchins, E. (1959). *Rigidity of behavior: A variational approach to the effect of Einstellung*. Eugene: University of Oregon Books.

- Lustig, C., & Hasher, L. (2001). Implicit memory is vulnerable to proactive interference. *Psychological Science*, 12, 408–412.
- Maher, M. L. (2010). Design creativity research: From the individual to the crowd. In T. Taura & Y. Nagai (Eds.), *Design creativity 2010* (pp. 41–48). London: Springer.
- Maier, N. R. F. (1930). Reasoning in humans: I. On direction. *Comparative Psychology*, 12, 115–143.
- Maier, N. R. F. (1931). Reasoning in humans: II. The solution of a problem and its appearance in consciousness. *Comparative Psychology*, 12, 181–194.
- Markman, A. B., Wood, K. L., Linsey, J. S., Murphy, J. T., & Laux, J. P. (2009). Supporting innovation by promoting analogical reasoning. In A. B. Markman & K. L. Wood (Eds.), *Tools for innovation* (pp. 85–103). New York: Oxford University Press.
- Martindale, C. (1981). *Cognition and consciousness*. Homewood, IL: Dorsey.
- Martindale, C. (1989). Personality, situation, and creativity. In J. A. Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 211–228). New York: Plenum.
- Martindale, C. (1995). Creativity and connectionism. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The creative cognition approach* (pp. 249–268). Cambridge, MA: MIT Press.
- Medin, D. L., & Shoben, E. J. (1988). Context and structure in conceptual combination. *Cognitive Psychology*, 20, 158–190.
- Mednick, M. T., Mednick, S. A., & Mednick, E. V. (1964). Incubation of creative performance and specific associative priming. *Journal of Abnormal and Social Psychology*, 69, 84–88.
- Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*, 69(3), 220–232.
- Metcalfe, J., & Weibe, D. (1987). Intuition in insight and noninsight problem solving. *Memory and Cognition*, 15(3), 238–246.
- Metcalfe, J. (1986). Premonitions of insight predict impending error. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 12, 623–634.
- Murphy, G. L., & Medin, D. L. (1985). The role of theories in conceptual coherence. *Psychological Review*, 92, 289–316.
- Nijstad, B. A., & Stroebe, W. (2006). How the group affects the mind: A cognitive model of idea generation in groups. *Personality and Social Psychology Review*, 10, 186–213.
- Nijstad, B. A., Stroebe, W., & Lodewijkx, H. F. M. (2003). Production blocking and idea generation: Does blocking interfere with cognitive processes? *Journal of Experimental Social Psychology*, 39(6), 531–548.
- Osborn, A. (1957). *Applied imagination*. New York: Scribner.
- Osherson, D. N., Smith, E. E., Wilkie, O., López, A., & Shafir, E. (1990). Category-based induction. *Psychological Review*, 97, 185–200.
- Patalano, A. L., & Seifert, C. M. (1997). Opportunism in planning. *Cognitive Psychology*, 34, 1–36.
- Reason, J., & Lucas, D. (1983). Using cognitive diaries to investigate naturally occurring memory blocks. In J. E. Harris & P. E. Morris (Eds.), *Everyday memory: Actions and absentmindedness* (pp. 53–69). London: Academic Press.
- Reitman, W. (1965). *Cognition and thought*. New York: Wiley.
- Rips, L. J. (1975). Inductive judgments about natural categories. *Journal of Verbal Learning and Verbal Behavior*, 14, 665–681.
- Roediger, H. L., III, & McDermott, K. B. (1995). Creating false memories: Remembering words not presented in lists. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 21, 803–814.
- Roediger, H. L., III, & Thorpe, L. A. (1978). The role of recall time in producing hypermnesia. *Memory and Cognition*, 6(3), 296–305.
- Rosch, E. H. (1973). Natural categories. *Cognitive Psychology*, 4, 328–350.
- Rosch, E. H. (1975). Cognitive reference points. *Cognitive Psychology*, 7, 532–547.
- Rosch, E. H., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology*, 8, 382–439.
- Schooler, J. W., & Melcher, J. (1995). The ineffability of insight. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The creative cognition approach* (pp. 97–134). Cambridge, MA: MIT Press.
- Seifert, C. M. (2008). Now why didn't I think of that? The cognitive processes that create the obvious. *Lewis & Clark Law Review*, 12(2), 489–507.
- Seifert, C. M., & Patalano, A. L. (2001). Opportunism in memory: Preparing for chance encounters. *Current Directions in Psychological Science*, 10(6), 198–201.
- Seifert, C. M., Meyer, D. E., Davidson, N., Patalano, A. L., & Yaniv, I. (1994). Demystification of cognitive insight: Opportunistic assimilation and the prepared-mind perspective. In R. J. Sternberg & J. E. Davidson (Eds.), *The nature of insight* (pp. 65–124). Cambridge, MA: MIT Press.
- Shah, J. J., Kulkarni, S. V., & Vargas-Hernandez, N. (2000). Evaluation of idea generation methods for conceptual design: Effectiveness metrics and design of experiments. *Journal of Mechanical Design*, 122, 377–384.
- Shah, J. J., Smith, S. M., & Vargas-Hernandez, N. (2003). Metrics for measuring ideation effectiveness. *Design Studies*, 24, 111–134.
- Shoben, E. J., & Gagne, C. L. (1997). Thematic relations and the creation of combined concepts. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 31–50). Washington, DC: APA Books.
- Sifonis, C. M., & Ward, T. B. (1998). Structural alignment in relational interpretations of conceptual combinations. In M. A. Gernsbacher & S. J. Derry (Eds.), *Proceedings of the Twentieth Annual Conference of the Cognitive Science Society* (pp. 968–973). Hillsdale, NJ: Erlbaum.
- Simonton, D. K. (1999). *Origins of genius: Darwinian perspectives on creativity*. Oxford, England: Oxford University Press.
- Smith, S. M. (1994). Getting into and out of mental ruts: A theory of fixation, incubation, and insight. In R. J. Sternberg & J. Davidson (Eds.), *The nature of insight* (pp. 121–149). Cambridge, MA: MIT Press.
- Smith, S. M. (1995a). Creative cognition: Demystifying creativity. In C. N. Hedley, P. Antonacci, & M. Rabinowitz (Eds.), *The mind at work in the classroom: Literacy and thinking* (pp. 31–46). Hillsdale, NJ: Erlbaum.
- Smith, S. M. (1995b). Fixation, incubation, and insight in memory, problem solving, and creativity. In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The creative cognition approach* (pp. 135–155). Cambridge: MIT Press.
- Smith, S. M. (2003). The constraining effects of initial ideas. In P. Paulus & B. Nijstad (Eds.), *Group creativity: Innovation through collaboration* (pp. 15–31). New York: Oxford University Press.
- Smith, S. M. (2008). Invisible assumptions and the unintentional use of knowledge and experiences in creative cognition. *Lewis and Clark Law Review*, 12(2), 101–116.

- Smith, S. M., & Blankenship, S. E. (1989). Incubation effects. *Bulletin of the Psychonomic Society*, 27(4), 311–314.
- Smith, S. M., & Blankenship, S. E. (1991). Incubation and the persistence of fixation in problem solving. *American Journal of Psychology*, 104, 61–87.
- Smith, S. M., Kerne, A., Koh, E., & Shah, J. (2009). The development and evaluation of tools for creativity. In A. B. Markman & K. L. Wood (Eds.), *Tools for innovation* (pp. 128–152). New York: Oxford University Press.
- Smith, S. M., & Tindell, D. R. (1997). Memory blocks in word fragment completion caused by involuntary retrieval of orthographically similar primes. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 23(2), 355–370.
- Smith, S. M., & Vela, E. (1991). Incubated reminiscence effects. *Memory and Cognition*, 19(2), 168–176.
- Smith, S. M., Ward, T. B., & Schumacher, J. S. (1993). Constraining effects of examples in a creative generation task. *Memory and Cognition*, 21, 837–845.
- Storm, B. C., & Angello, G. (2010). Overcoming fixation: Creative problem solving and retrieval-induced forgetting. *Psychological Science*. doi: 10.1177/0956797610379864.
- Suwa, M., & Tversky, B. (2001). Constructive perception in design. In J. S. Gero & M. L. Maher (Eds.), *Computational and cognitive models of creative design* (pp. 227–239). Sydney, Australia: University of Sydney.
- Tversky, B. (2001). Spatial schemas in depictions. In M. Gattis (Ed.), *Spatial schemas and abstract thought* (pp. 79–111). Cambridge, MA: MIT Press.
- Tversky, B. (2005). Functional significance of visuospatial representations. In P. Shah & A. Miyake (Eds.), *Handbook of higher-level visuospatial thinking* (pp. 1–34). Cambridge: Cambridge University Press.
- Tversky, B., & Hard, B. M. (2001). Embodied and disembodied cognition: Spatial perspective-taking. *Cognition*, 110, 124–129.
- Tversky, B., & Suwa, M. (2009). Thinking with sketches. In A. B. Markman & K. L. Wood (Eds.), *Tools for innovation: The science behind the practical methods that drive new ideas* (pp. 75–84). New York: Oxford University Press.
- Vargas-Hernandez, N., Shah, J. J., & Smith, S. M. (2010). Understanding design ideation mechanisms through multilevel aligned empirical studies. *Design Studies*, doi:10.1016/j.destud.2010.04.001.
- Vul, E., & Pashler, H. (2007). Incubation benefits only after people have been misdirected. *Memory and Cognition*, 35(4), 701–710.
- Ward, T. B. (1994). Structured imagination: The role of conceptual structure in exemplar generation. *Cognitive Psychology*, 27, 1–40.
- Ward, T. B. (1995). What's old about new ideas? In S. M. Smith, T. B. Ward, & R. A. Finke (Eds.), *The creative cognition approach* (pp. 157–178). Cambridge, MA: MIT Press.
- Ward, T. B. (2009). ConceptNets for flexible access to knowledge. In A. B. Markman & K. L. Wood (Eds.), *Tools for innovation* (pp. 153–170). New York: Oxford University Press.
- Ward, T. B., Dodds, R. A., Saunders, K. N., & Sifonis, C. M. (2000). Attribute centrality and imaginative thought. *Memory and Cognition*, 28, 1387–1397.
- Ward, T. B., Guerdat, M. G., & Roskos, B. (2010, November). *Avatar visibility as a potential detrimental factor in virtual brainstorming*. Paper presented at the Annual Meeting of the Psychonomic Society, St. Louis, MO.
- Ward, T. B., Patterson, M. J., & Sifonis, C. (2004). The role of specificity and abstraction in creative idea generation. *Creativity Research Journal*, 16, 1–9.
- Ward, T. B., Patterson, M. J., Sifonis, C. M., Dodds, R. A., & Saunders, K. N. (2002). The role of graded structure in imaginative thought. *Memory and Cognition*, 30, 199–216.
- Ward, T. B., & Sifonis, C. M. (1997). Task demands and generative thinking: What changes and what remains the same. *Journal of Creative Behavior*, 31, 18–32.
- Weisberg, R. W. (1992). Metacognition and insight during problem solving: Comment on Metcalfe. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 18, 426–431.
- Weisberg, R. W. (2006). Modes of expertise in creative thinking: Evidence from case studies. In K. A. Ericsson, N. Charness, P. Feltovich, & R. R. Hoffman (Eds.), *Cambridge handbook of expertise and expert performance* (pp. 761–787). Cambridge, England: Cambridge University Press.
- Weldon, M. S., & Bellinger, K. D. (1997). Collective memory: Collaborative and individual processes in remembering. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23, 1160–1175.
- Wiley, J. (1998) Expertise as mental set: The effects of domain knowledge in creative problem solving. *Memory and Cognition*, 26, 716–730.
- Wilkenfeld, M. J., & Ward, T. B. (2001). Similarity and emergence in conceptual combination. *Journal of Memory and Language*, 45, 21–38.
- Wisniewski, E. J. (1997). Conceptual combination: Possibilities and aesthetics. In T. B. Ward, S. M. Smith, & J. Vaid (Eds.), *Creative thought: An investigation of conceptual structures and processes* (pp. 51–81). Washington, DC: APA Books.
- Yaniv, I., & Meyer, D. E. (1987). Activation and metacognition of inaccessible stored information: Potential bases for incubation effects in problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 13, 187–205.