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Errors in creative thought? Cognitive biases in a complex processing activity

ABSTRACT

The generation of new ideas is a complex demanding activity involving multiple processing operations. As is the case in other forms of complex cognition, biases in process execution can induce errors that limit peoples' ability to generate viable new ideas. In the present effort, the nature of these biases, and their impact on creative thought, are examined. It is noted that these biases arise from multiple sources including knowledge, limitations in processing capacity, patterns of information use, and the strategies applied in process execution. The implications of these observations for enhancing creative performance are discussed along with potential strategies for error remediation.

INTRODUCTION

Edison's success as an inventor is unquestioned. He failed to develop a successful telephone, however, apparently because the model he applied in developing his approach was inherently flawed (Carlson & Gorman, 1992). Xerox developed the first viable prototype for the personal computer yet it failed to exploit this technology. Andy Warhol's art was a success yet his movies were abysmal failures in both a commercial and an artistic sense. These examples suffice to make a point — capacity, effort, even viable initial ideas, do not insure the success of creative efforts. The fact that failure is common in creative work (Huber, 1978; Sharma, 1999), however, begs a question. What causes people to fail?

Initial attempts to account for these failures focused on potential errors in creative thought (Gibson & McGarvey, 1937). For example, studies by Duncker (1935) and Maier (1933) indicated that that premature adoption of a mental set leads to fixation on a particular approach which makes it difficult for people to generate alternative solutions to novel problems. Chant (1933), in a comparison of good and poor performance on a novel problem-solving task, found that poor performance was associated with a tendency to rely on prior experience rather than focusing on the data at hand.

With a few notable exceptions (Brightman, 1975; Finke, Ward, & Smith, 1992; Kaufmann, 1991; Smith, 1997), recent studies have not stressed the role of cognition in understanding error in creative thought. Instead, two alternative models have been applied. One of these models holds that error is an inherent aspect of creative thought, potentially a beneficial aspect, as people capitalize on error, to take advantage of serendipitous juxtapositions (Rothenberg, 1987, 1994) and use these juxtapositions as a basis for the progressive refinement of new ideas (Feiner & Holden, 1993). The other current model places less emphasis on the potential value of errors. In this social inhibition framework, errors are attributed to situational variables, for example social loafing, conformity pressure, and evaluation pressures, that act to inhibit creative thought (Amabile, 1988; Amabile & Gryskiewicz, 1989; Jones, 1977; Magyari-Beck, 1992).

Although there is value in these alternative conceptions of error, recent advances in our understanding of creative cognition (Brophy, 1998; Lubart, 2001; Mumford & Gustafson, 1988; in press; Finke, Ward, & Smith, 1992) have indicated that the influence of cognition on errors in creative thought warrants reexamination. Accordingly, our intent in this article is to examine the kind of cognitive variables that lead to errors in peoples' creative problem-solving efforts. Before turning to these likely sources of error, however, it would seem germane to briefly review certain critical features of peoples' creative problem-solving activities.

CREATIVE THOUGHT

Cognition

Of course, not all problems call for creative thought (Mumford, Whetzel, & Reiter-Palmon, 1997). Creative thought occurs on problems that require new, novel solutions, or at least solutions that are novel to the individual (Ghiselin, 1963; Mumford & Gustafson, 1988). Although creative problems call for a novel response, these problems typically display three other characteristics that shape both creative thought and the kind of errors likely to be observed in peoples' creative efforts. First, creative problems tend to be ill-defined in the sense that problem elements and structure are not given or immediately apparent (Freidricksen & Ward, 1978; Glover, 1979). Second, creative problems tend to be complex in the sense that they involve multiple pieces of information and multiple processing activities (Mumford, Mobley, Uhlman, Reiter-Palmon, & Doares, 1991). Third, creative problems are typically dynamic in nature with solutions unfolding over time as people work through the problem at hand (Wentorf, 1992).

These characteristics of creative problems have a number of implications for the nature of peoples' creative problem-solving activities. To begin, by virtue of their complexity, dynamism, and lack of definition, creative problem-solving efforts are typically associated with a high degree of uncertainty. These characteristics of creative problems also imply that multiple paths will be available to reach a solution and that decisions must be made, decisions under uncertainty, as to what paths will be pursued and what actions will be taken (Hogarth, 1980; Perkins, 1992). Finally, the proposition that creative problems are ill-defined, dynamic, and complex implies that people must make these decisions in such a way that they can simultaneously impose structure on their problem-solving activities while successfully exploiting emergent opportunities and new information (Drazin, Glynn, & Kazanjian, 1999; Lowendahl, 1995).

To generate structure, make decisions about their actions, and formulate problem solutions, people rely on knowledge (Mumford, Mobley, Uhlman, Reiter-Palmon, & Doares, 1991; Scott, Lonergan, & Mumford, in press). In fact, the available evidence indicates that expertise is a significant influence on performance in most creative problem-solving efforts (Ericsson & Charness, 1994; Weisberg, 1999). Expertise, however, should not be viewed as a simple accumulation of discrete bits of information. Instead, expertise involves the construction of principle-based structures for organizing, and imposing meaning on, information lying in some domain (Chi, Feltovich, & Glaser, 1984; Glaser, 1987; Holyoak, 1990). The principle-based organizing structures used by experts facilitate information acquisition, direct attention, reduce processing demands, permit more rapid identification of critical events, and allow experts to project the consequences of their actions (Adams & Ericsson, 2000; Anzai, 1984; Isenberg, 1986).

These principal-based organizing structures play a key role in creative thought. In fact, their development may represent a noteworthy creative performance in its own right (Gruber, 1994; Tweney, 1992). Nonetheless, other forms of knowledge may be involved in expert performance. Experts have substantial experience in applying knowledge in real-world settings. These real-world incidents, or cases, are used by experts in structuring problems, evaluating events, and drawing conclusions about requisite actions (Hammond, 1990; Kolodner, 1993). Along with the acquisition of experiential cases, moreover, experts develop a rich body of associational connections or tacit knowledge (Hedlund, Forsythe, Horvath, Williams, Snook, & Sternberg, 2003; Reber, 1989) — associations known to play a potentially significant role in creative thought (Gruszka & Necka, 2002).

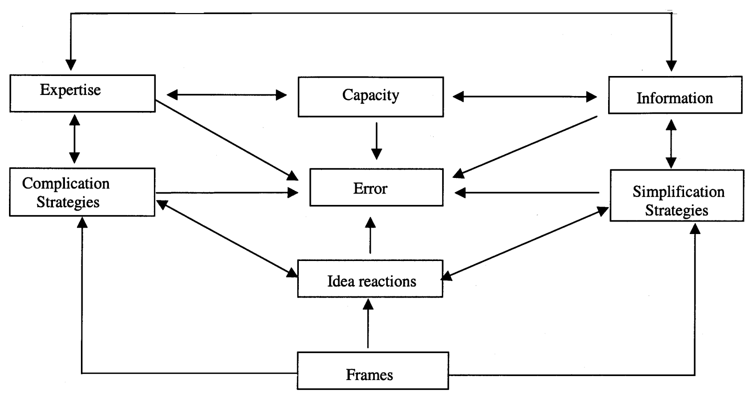
If people had only extant knowledge to work with, it would be impossible for people to create new problem solutions. Accordingly, most students of creativity stress the role of processing activities as a key element of creative thought (Merrifield, Guilford, Christensen, & Frick, 1962; Parnes, 1976; Sternberg, 1988). Research on the processes involved in creative problem-solving has shown that a number of processes are involved in most creative problem- solving efforts (Basadur, Runco, & Vega, 2000; Brophy, 1998; Lubart, 2001; Mumford, Mobley, Uhlman, Reiter-Palmon, & Doares, 1991; Ward, Smith, & Finke, 1999) including 1) problem construction, 2) information gathering, 3) concept selection, 4) conceptual combination, 5) idea generation, 6) idea evaluation, 7) implementation planning, and 8) monitoring. Effective execution of these processes, as reflected in application of appropriate heuristics, or process execution strategies, has been shown to be related to performance on a number of creative problem-solving tasks (Mumford, Supinski, Baughman, Costanza, & Threlfall, 1997; Scott, Lonergan, & Mumford, in press).

With regard to these processing activities, however, three further points should be borne in mind. First, the available evidence indicates that effective execution of all these processes is difficult and demanding requiring substantial attentional resources, as well as conscious analytic appraisal, on the part of problem solvers (Rothenberg, 1987; Sternberg & Lubart, 2003). Second, these processes might all be executed using a number of different heuristics, or process execution strategies, only some of which are positively related to successful creative problem-solving efforts (Baer, 2003). Thus, Mumford, Baughman, Supinski, and Maher (1996) found that use of information gathering strategies focusing on key facts and anomalies was related to the quality and originality of obtained solutions on a set of novel management and public policy problems but not a search for a wide array of information. Third, these processes appear to operate as an interdependent system such that the outcomes of one set of processing operations, for example conceptual combination, provide the basis for other operations, for example idea generation (Estes & Ward, 2002).

Error Model

The nature of the cognitive operations involved in creative thought suggests that errors may arise from a number of sources. Figure 1 presents a model of the mechanisms giving rise to error. As noted earlier, creative thought is a complex, demanding activity (Baughman & Mumford, 1995). These demands, in turn, suggest that limitations in human information processing capacity will lead to error through restrictions on information acquisition and application of inappropriate simplification strategies in process execution. Even when capacity is adequate to the task, however, the kind of information sought, and the particular strategies applied, may induce error. For example, undue extension of information search activities may inhibit effective conceptual combination.

FIGURE 1. Model of error influence.



Of course, one way people handle capacity demands is through the acquisition of expertise (Ericsson & Charness, 1994). Expertise, however, brings with it preexisting knowledge structures that may, in turn, lead to error (Minsky, 1997). The more complicated, and elaborate, knowledge structures applied by experts may, at times, also lead to unnecessary complications that result in error by inducing additional, potentially unmanageable, processing demands.

The possibility of error, or the perception one might fail, leads people to react to new ideas. Reactions to potential failures may result in the use of strategies intended to minimize error.

Attempts to avoid error, however, may in fact, lead to error — for example, overly critical appraisals of new ideas during idea evaluation. By the same token, however, the excitement that surrounds generation and implementation of new ideas may engender a predisposition toward errors of optimism. Finally, the framing activities used to define and structure problems will influence not only idea reactions but also the strategies people apply in problem-solving — at times leading people to apply ineffective problem-solving strategies.

ERRORS
Expertise

Although knowledge and expertise are necessary for creative thought, it has been argued that, past a point, greater expertise may not necessarily contribute to creativity (Mumford & Gustafson, 1988; Sternberg, 1996, 1994). The apparent curvilinear, inverted U, relationship between expertise and creativity might, in principal, be attributed to the potential effects of expertise on error. One error commonly observed at high levels of expertise arises from the availability of frequently used, and readily accessible, cases for defining and structuring problem situations. In one study along these lines, Hershey, Walsh, Read, and Chulef (1990) examined the performance of financial planners in developing plans for hypothetical clients. Using think aloud protocols, they found that experts' errors, as opposed to novices' errors, occurred because experts tended to automatically apply common, frequently used, case models in defining and structuring problems. Similar findings have been reported by Frensch and Sternberg (1989) in a review of the effects of expertise on problem-solving. Thus, expertise, at times, may lead people to ignore, or discount, unique aspects of the problem situation thereby undermining performance in problem construction.

Over reliance on common case models, however, is not the only error that might be induced by expertise. Expertise, or knowledge about a domain, is associated with the formation of beliefs about the causes of relationships among events (Frankwich, Walker, & Ward, 1994). In fact, the development of complex, well-articulated mental models describing event interdependencies is commonly considered a hallmark of expertise (Adams & Ericsson, 2000; Cannon-Bowers, Salas, & Converse, 1993). However, the availability of these mental models opens up a new possibility for error.

Moskowitz and Sarin (1983) examined the kind of errors made by security analysts vis-à-vis the consistency of their assessments. They manipulated the kind of information presented — specifically, they contrasted causal versus diagnostic information and information bearing on positive and negative relationships. They found that people tended to rely on known causal relationships, in particular positive causal relationships, in making assessments. As a result, people may discount the value of eliminating implausible explanations and fail to consider complex relationships in generating creative problem solutions. Similar findings have been described by Doerner and Schaub (1994), Hogarth and Makridakis (1981), and Minsky (1997). What is of note here, however, is that the tendency to impose extant causal models on event interpretations may lead to errors in creative thought (Woodman, Sawyer, & Griffin, 1993).

Some support for this proposition has been provided by both a) quantitative experimental studies of creativity, and b) qualitative historic studies of noteworthy technical innovations. In an experimental study of creativity, Ward (1994) asked undergraduates to describe, through drawings, aliens that had evolved under conditions different than those on earth. They found that the originality of the obtained drawings was constrained by preservation of relationship models describing human attributes (e.g. bilateral symmetry). In a qualitative comparison of Edison and Bell in the development of the telephone, Carlson and Gorman (1992) found that Edison's failure in this regard could be traced to his use of a mental model developed as part of his prior work on the telegraph — a model that involved assumptions that were not especially useful with regard to voice transmission.

Errors arising from experts' use of well-developed mental models might be attributed to any one of three potential mechanisms. First, by virtue of their familiarity with and commitment to a mental model, experts may, at times, discount certain causes, or approaches, particularly causes and approaches that do not fit with extant mental models (Kuhn, 1970). Second, problems will be defined and solutions attempted within the framework provided by available models thereby limiting the range of problem solutions attempted (Brightman, 1978). Third, and finally, the information sought for use in problem-solving may be structured in terms of available models, and their associated causal assumptions, leading people to ignore or discount certain types of information and certain types of relationships (Watkins, 1983).

Another way experts differ from novices is that they have available a larger of number of categories for organizing and understanding the events that occur within a domain (Chi, Bassock, Lewis, Reimann, & Glaser, 1989). Their categories, or concepts, moreover, tend to be more sharply defined with respect to attributes of relevant exemplars (Lee, MacGregor, Bavelas, Mirlin, & Newman, 1988). With regard to potential errors in creative thought, these characteristics of experts' knowledge structures are noteworthy for two reasons. First, although sharp concept differentiation may make conceptual combination, and the subsequent generation of new ideas, more likely by providing people with a larger number of concepts to work with, this differentiation may also make conceptual combination more difficult. Second, as categories become over determined through the availability of multiple well structured exemplars, the addition of new exemplars is likely to have less impact on category structure resulting in a tendency, among experts, to overlook the significance of certain kinds of new information in idea generation.

Although it seems clear that the concepts and cases available to experts can induce a proclivity towards certain kinds of errors in creative thought, little has been said to this point about the role of associational knowledge. Associations are activated through surface similarities in co-occurring events rather than an active analysis of underlying structural relationships (Jacoby, 1991). This point is of some importance because it suggests that experts, at least at times, may rely on tacit knowledge and perceived similarities rather than an in-depth analysis of the problem. This failure to analyze implications is particularly likely to occur in processing operations, such as problem construction and idea evaluation, where comparative evaluations are involved (Mumford, Lonergan, & Scott, in press) resulting in a failure to recognize creative ideas and/or the need for creative ideas to address the problem at hand.

Information

Creative thought, like other forms of problem-solving, ultimately depends on information. In his analysis of fixation error, Smith (1997) has shown how information accessibility can be used to account for this phenomenon. He argued that cues in the problem situation activate frequent and recent associations. These activated associations, in turn, can block the retrieval of, or search for, other kinds of information that might lead people to pursue a novel solution path. Thus, breaks or time away, by reducing activation of certain associations, can lead to the sudden emergence of a new idea or approach.

What should be recognized here, however, is that accessibility errors may be induced through conscious as well as unconscious, associational, mechanisms. Information gathering and storage is a resource intensive, time consuming activity. As a result, people often rely on available information. Thus, Anderson, Glassman, McAfee, and Pinelli (2001) found, in a study of research and development laboratories, that scientists were more likely to rely on local verbal sources of information than less accessible, more resource intensive, sources such as journal articles, professional meetings, and benchmarking. This bias towards the use of readily available information will, in turn, limit exploration of the problem space thereby reducing the creativity of subsequent solutions (Perkins, 1992).

In addition to accessibility, people appear to bias information search and retrieval towards salient information. Undue reliance on salient information, goal relevant, visible, socio-emotionally evocative information, may, however, prove to be a noteworthy source of error (Fiske, 1982; Weick, Gilfillan, & Keith, 1976). This point is illustrated in a recent study by Clark and Montgomery (1999). They examined managers' reactions to putative competitors on a novel business planning task. It was found that managers overweighed information provided by the actions of large, historically successful, competitors. Use of salient information not only restricts information search, it may overwhelm, or mask, other available information while directing search activities along obvious avenues (Huckauf & Heller, 2002) — all factors inhibiting the production of new ideas.

Errors attributable to salience and accessibility effects, however, may, at least to some extent, be offset by another characteristic of peoples' information gathering activities. When people are presented with complex, significant problems, as is the case in most real-world creative efforts, people tend to extend information search (Culnan, 1983). Extended information search, however, may induce another set of errors.

One way extended search may lead to errors in creative thought involves allocation of cognitive resources. More specifically, time and resources spent gathering information is time and resources that must be taken away from other processing activities. Another way that extended search may induce error is by activating multiple tangential categories — a phenomenon that makes conceptual combination and subsequent idea generation more difficult. Finally, in creative efforts, by virtue of their dynamism, initial information gathering must be used to structure subsequent information search (Chorba & New, 1980; Karni, 1985). By overwhelming attentional capacity, overly extended initial search may reduce flexibility and constrain subsequent processing activities thereby inhibiting creative thought. These observations, in turn, point to a broader conclusion. More specifically, effective information use in creative problem-solving requires balanced information gathering, typically information gathering activities focusing on key facts, relevant diagnostic information, and anomalies (Newman, 1980).

The need for targeted, just sufficient information, of course, implies that judgment is required in information gathering. The need for judgment, however, opens up the possibility that another form of error might influence creative thought. Judgments about the relevance of information are influenced by both the individual's intent and the conceptual structures with which they approach available information (Blaylock & Rees, 1984; Hilton & Swieringa, 1982; Lowe & Steiner, 1968). As a result, relevant information that falls outside the individual's interpretive framework, often anomalous or incongruent information, may not be attended to, and encoded, resulting in error. This observation reinforces the oft noted point that creative thought improves when observations are examined from a number of different perspectives (Dunbar, 1995).

Capacity

One of the most clear cut findings to emerge in studies of problem-solving is that human information processing capacity is limited. People can attend to, and work with, only a limited amount of information and have difficulty in working with complex relationships of the sort encountered in most creative efforts (Doerner & Schaub, 1994; Fischer, 1979; Hubert, 1975; Bazerman, Moore, Tenbrunsel, Wade-Benzoni, & Blount, 1999; Gilliam, Hoffman, Marler, & Wynn-Darcy, 2002). In one recent study examining errors in mathematical problem-solving, Ayres (2001) found that errors were more likely to arise as a result of excessive processing demands than failure to master relevant techniques.

One way capacity limitations inhibit creative thought is that they inhibit effective process execution. Ward and his colleagues (Estes & Ward, 2002; Finke, Ward, & Smith, 1992; Ward, Smith, & Finke, 1999) have shown that the generation of new ideas requires elaboration and exploration of the features emerging from conceptual combination efforts. When capacity is limited by factors such as prior commitments, excessive task difficulty, and fatigue, extended exploration and elaboration becomes less feasible, thereby limiting peoples' capacity for creative thought.

Capacity limitations may also induce errors in creative problem-solving by inhibiting the critical analysis of creative processing activities (Cosier & Rose, 1977). Successful creative efforts require careful evaluation of information for reliability, credibility, and relevance (Derow, 1980; Mann, 1989; Raisbeck, 1979). Moreover, in process execution, outputs must be evaluated (Parnes & Noller, 1972; Treffinger, 1995) with these evaluations of output providing a basis for extending initial efforts and redirecting these efforts to enhance performance. In other words, creative thought depends on critical thought (Abra, 2003; Gorman & Plucker, 2003). Critical thought, however, implies a resource intensive analysis of process execution strategies where people must question prior work. When capacity limitations make it difficult for people to question their work, they are less likely to generate high quality (Ennis, 1987), original (Rothenberg, 1979) solutions to novel problems.

In addition to these effects on process execution, capacity limitations may induce coping strategies that, while reducing processing demands, simultaneously have the potential for inducing errors in creative thought. One strategy people apply in attempts to manage capacity limitations is to reduce complexity through isolation. In isolation people adapt more narrow decision frames working through parts of the problem rather than the problem as a whole (Bercovitz, deFigueiredo, & Teece, 1997; Dosi & Lovallo, 1997; Kahneman & Lovallo, 1993). However useful isolation may be as a strategy for reducing capacity demands, it is a likely source of error in creative thought. To begin, conceptual combination depends on concept integration and, as the range of concepts under consideration becomes narrower, creativity is likely to suffer (Baughman & Mumford, 1995; Mobley, Doares, & Mumford, 1992). Moreover, when problems are broken into isolated parts, it becomes more difficult for people to recognize mistakes made in earlier processing activities and adapt their activities to dynamic, emerging aspects of the problem situation (Mumford, Schultz, & Osburn, 2002). Finally, when problems are broken into parts, it becomes easier for people to discount broader contextual influences on their activities, for example restrictions, resource requirements, and evaluation expectations, which influence peoples' ability to generate workable new solutions.

Another strategy used to reduce capacity demands, a strategy also likely to induce error, might be described as fixing. In fixing, variable elements of the problem situation, for example multiple goals or changes over time in the requirements for requisite problem-solving activities, are discounted or ignored. By removing these variable elements, processing demands are reduced. However, fixing can, in particular when it leads people to ignore critical elements of the problem, induce errors in creative thought. Some support for this observation may be found in Doerner and Schaub (1994). They found, in a series of experimental studies, that errors in forecasting, one capacity involved in creative thought (Berger, Guilford, & Christensen; 1957; Mumford 2001), could be traced to a) failure to consider multiple competing goals, b) failure to consider multiple non-linear relationships, c) oversimplification of complex causal relationships, d) discounting side effects, and e) failure to consider multiple consequences, particularly negative consequences.

A final strategy used to reduce capacity demands involves the type of material used in creative problem-solving. People have difficulty working with abstract concepts. As a result, capacity demands can be reduced by focusing on immediate concrete issues and events (Borgida & Nisbitt, 1977; Hogarth & Makridakis, 1981; Kahneman & Tversky, 1982; Sykes & Johnson, 1999). This focus on concrete material, however, will make it difficult for people to identify the features, metaphors, and analogies needed in conceptual combination. Moreover, this focus on concrete material may make it more difficult for people to identify emergent features and identify the consequences of implementing new ideas — all effects that would limit the likely success of peoples' creative efforts.

Simplification

The strategies used to manage capacity limitations are related to another set of biases that might lead to errors in creative thought. Here we refer to the various simplification strategies commonly held to induce bias on decision-making tasks (Hogarth & Makridakis, 1981; Morera & Budescu, 2001; Tversky & Kahneman, 1974, 1982; Winkler, 1982; Wright, 1980). Although many of the biases observed in decision-making are not necessarily relevant to creativity, three of these biasing factors are worthy of note: 1) representativeness, 2) illusory correlation, and 3) anchoring.

Categories, or concepts, are defined in terms of exemplars with exemplars being structured in terms of certain features. Typical features and exemplars are more easily retrieved and provide the preferred basis for working with concepts in problem-solving (Mobley, Doares, & Mumford, 1992). The bias towards the application of typical features and typical exemplars (robins and wings versus owls and talons) is a representativeness bias — a bias that appears to inhibit the production of new ideas. In one study along these lines, Baughman and Mumford (1995) asked undergraduates to work on a series of category combination problems. They found that the production of high quality, original ideas was inhibited by the use of typical features. Apparently, the tendency to rely on mundane, readily accessible, attributes of a concept reduces the chance that new features will emerge in conceptual combination thereby inhibiting idea generation (Estes & Ward, 2002). In keeping with this conclusion, Rothenberg (1973, 1979) found that creative undergraduates, as opposed to their less creative counterparts, were more likely to generate contradictory or oppositional associations when presented with ambiguous stimuli.

Most categories, of course, are structured in terms of multiple features. When an object, or event, is assigned to a given category, the features of other category members are ascribed regardless of whether or not these features are, in fact, evident in the case at hand. This ascription of unobserved features is, of course, a manifestation of illusory correlation. Evidence that the phenomenon of illusory correlation can bias creative thought has been provided by Ward (1994). He found that when undergraduates were instructed to draw a feathered alien, the resulting drawings typically displayed two other key features of birds — a beak and wings. The existence of these illusory correlation effects is problematic, in part, because such effects may mask unique features, and new emergent features, in conceptual combination efforts. In part, however, the imposition of assumed features may prove problematic because it can impose an inappropriate, overly restrictive, structure on peoples' creative problem-solving activities.

Anchoring biases may exert similar effects on peoples' creative problem-solving efforts. In anchoring, an initial estimate, or an initial concept, is selected for appraising the problem at hand and defining solution parameters. This initial appraisal, or idea, is adjusted as new information becomes available. The error due to anchoring arises from the fact that these adjustments are made too slowly given the new information available (Tversky & Kahneman, 1982). In the case of creative problem-solving, the operation of anchoring biases implies two errors. First, people will persist too long following an initial solution path, although this path, in the long run, will prove ineffective. Second, information gathered as people elaborate new ideas and explore their implications will be underweighted thereby inhibiting adaptive refinement and requisite revision.

Performance Frames

Another type of error commonly observed on decision-making tasks involves construal of the task at hand. These errors, commonly referred to as framing errors, are evident in shifts in peoples' decisions, from a hypothetical ideal, as a function of the potential for gains or losses described in initial descriptions of the decision task (Hogarth, 1980). Framing, in this sense, involves the imposition of assumptions about the nature of the problem (Bercovitz, deFigueiredo, & Teece, 1997). Given the ill-defined nature of creative problems, some form of framing may well be necessary. When framing leads to inappropriate assumptions about the nature of the problem, however, errors may emerge (Kaufmann, 1989). In fact, the need to induce structure on ill-defined problems may be one reason why framing errors seem pervasive in creative thought. A case in point may be found in the development of powered flight where failure to frame the problem as a problem of control rather than lift led to numerous failures prior to the Wright brothers reframing of the problem.

One illustration of the role of these assumptional errors in creative thought may be found in the phenomenon of functional fixedness (Duncker, 1945). These fixation errors arise because prior experience leads people to make assumptions about appropriate and feasible uses of an object. These assumptions about object use tend to block, or inhibit, the identification of alternative uses for an object. Along similar lines, the way a problem is presented, and the context in which it arises, may lead to assumptions about the nature of requisite problem-solving activities. An illustration of this kind of error is provided by Scheerer's (1963) nine dot problem where a solution requires people to "think outside the box".

The fact that assumptions about the nature of the problem can induce error, of course, broaches the issue of satisficing. In satisficing the most readily available representation of the problem situation is retrieved from memory and used as a basis for problem construction. Errors arise as a result of failure to analyze alternative representations in relation to the underlying structure of the problem situation (Mumford, Reiter-Palmon, & Redmond, 1994).

The role of experiential representations and assumptions in satisficing and fixation point to another set of errors likely to have a particularly pernicious influence on real world creative problem-solving efforts. By virtue of their education and experience, people tend to assume that any problem-solving effort must have a single, given, goal. Accordingly, people often try to structure their problem-solving activities by reference to the goals held to be operating in the problem situation at hand. In a series of studies examining the heuristics involved in problem construction and concept selection, Mumford and his colleagues (Mumford, Baughman, Threlfall, Supinski, & Costanza, 1996; Mumford, Supinski, Threlfall, & Baughman, 1996) found that the tendency to use goals, as opposed to procedures and requisite information, as a basis for structuring problem-solving activities led to the production of less original and lower quality solutions on a set of creative problem-solving tasks.

One reason the use of a priori goals as a basis for structuring problem-solving activities tends to inhibit creative thought may be attributed to the fact that goal framing can induce means-end analysis where people work backwards from the goal to a problem solution. Means-end analysis, however, is a time consuming trial and error strategy that reduces the cognitive carrying capacity needed for creative thought (Kaizer & Shore, 1995). Another reason the use of given goals as a structuring mechanism tends to inhibit creative thought is attributable to the inflexibility that arises from the escalating commitment associated with public commitment to a goal and initial investment in a particular solution path (Duhaime & Schwenk, 1985). A final reason the use of goals as a structuring mechanism induces error is that with motivated pursuit of given goals people are both less likely to a) invest resources in critical analysis (Gollwitzer & Brandstatter, 1997; Gollwitzer & Kinney, 1989), and b) consider aspects of the problem situation that might block attainment of the goals being pursued (Gehm, 1984).

Risk Aversion

Earlier, we noted that creative problems require a novel solution to a poorly structured problem. The ill-defined, novel nature of creative problems implies that goal attainment, the success of the venture, cannot be insured. Thus, from the perspective of the individual involved, creative efforts are an inherently risky undertaking (Bergstroem, 1991; Hall, 1980). In keeping with the conclusion, creative achievement, and presumably involvement in creative problem-solving, has been found to be related to dispositional measures examining peoples' propensity for risk-taking (Barron & Harrington, 1981, MacKinnon, 1962). Although creative efforts involve risk, the bulk of the available evidence indicates that people are risk averse (Ahituv & Wand, 1984; Gowada, 1999; Newman, 1980; Tversky & Kahneman, 1974). Peoples' apparent risk aversion is noteworthy in the context of the present discussion because some of the strategies used to manage risk during the course of creative problem-solving efforts may give rise to error.

One error associated with risk aversion is likely to appear during idea evaluation. A bias towards risk aversion implies that people will tend to evaluate ideas, and presumably reject ideas, that imply undue risk — particularly risk with regard to outcomes. Although the rejection of ideas, potentially premature rejection of ideas, can be traced to perceptions of outcome loss, often financial (Bercovitz, deFigueiredo, & Teece, 1997; Hitt, Hoskisson, Johnson, & Mosel, 1996; Sharma, 1999), more subjective personal considerations may lead people to reject novel, and potentially risky, solutions. For example, Shefrin and Statmen (1985) have argued that the maintenance of pride and self-esteem, along with aversion to regret, may lead people to reject a risky course of action. Presumably, similar concerns may lead people to reject novel ideas that might fail, and fail in public.

Although risk may lead to the premature rejection of potentially viable ideas, risk aversion may have a number of other more subtle, but potentially more pernicious, effects. One of these effects involves an unwillingness to make decisions. People can reduce risk in creative efforts by avoiding commitment to a particular course of action. In fact, Gilbert and Ebert (2002) and Lovallo and Kahneman (2000) have provided evidence indicating that people prefer courses of action that allow them to change their minds. Although this bias towards flexibility may, at times, prove of value in creative ventures, it may also induce error when people prove unable to commit to a course of action. This tendency to avoid commitment to a course of action will prove particularly problematic when there is a need to persist despite negative feedback and initial failure (Sternberg, 2000; Wild, 1992).

Another strategy that might be used to reduce risk results in a related error. As noted earlier, people value information (Hilton & Swieringa,1982). Information gathering, however, can also be used as a strategy for reducing risk. This phenomenon is illustrated in a study by Cecil and Lundgren (1978). They induced threat through time pressure in an experimental study of undergraduate decision making. In this study, time pressure led people to engage in more rechecking of available information. This extended search activity, however useful in some circumstances, may result in an overinvestment of scarce cognitive resources in information gathering and critical analysis thereby limiting the time people have available for conceptual combination and idea generation.

A third strategy that people might use to reduce risk in creative problem-solving is described, albeit obliquely, in a study by Morera and Budescu (2001). They asked students to make decisions about six potential apartment rentals using conditions where the *overall* advantages and disadvantages of each potential rental were described, and under conditions where the best and worst *attributes* of each rental alternative were described. They found that an analysis of discrete rental attributes, an analysis held to reflect use of a decomposition strategy, resulted in fewer errors. Although analytic decomposition may lead to error reduction and risk minimization, creative problems by virtue of their complexity and dynamism, cannot always be decomposed and decomposition may, at times, inhibit the intuitive appraisals known to play a significant role in creative thought (Peters, Hammond, & Summers, 1979; Policastro, 1995).

Optimism

One of the paradoxes of human cognition is that while people are risk averse they also tend to be optimistic (Weinstein, 1989). Gollwitzer and his colleagues (Gollwitzer, 1999; Gollwitzer & Brandstatter, 1997; Gollwitzer & Kinney, 1989) have argued that people manage these contradictory reactions through timing with people being more analytical and risk averse prior to engaging in an activity while becoming more optimistic after they have initiated action.

Recognition of this tension between risk aversion and optimism led Garvo, Nayyar, and Shapira (1997) to argue that two types of errors will be observed in the creative thought. More specifically, they argued that people can err through either a) overly optimistic appraisals of new approaches or new ideas or b) overreliance on proven approaches and ideas. In their view, like that of Gollwitzer (1999), the impact of these errors on performance depends on timing and the conditions of task performance with errors of optimism proving particularly problematic when the conditions at hand are such that adequate support is not available for creative efforts. Essentially, optimism, often optimism induced by work on an idea, can lead to errors by causing people to overlook the requirements and constraints impinging on idea development.

These observations about optimism bias are noteworthy because they point to two kinds of errors likely to arise when people have become committed to an idea. One of these errors arises from a bias towards confirmation (Feist & Gorman, 1998; Nickerson, 1998). Confirmatory bias involves a selective search for, and appraisal of, information that serves to support a priori expectations (Koriat, Lichtenstein, & Fischoff, 1980). While confirmatory bias is observed in many areas of human endeavor (Nickerson, 1998) it is particularly problematic, and perhaps unusually pervasive, in creative efforts because these efforts require a substantial investment of time, resources, and prestige in the development and fielding of a new idea. In other words, peoples' investment in their ideas promotes confirmatory biases that lead to error by blocking exploration, examination of alternative concepts, and critical thought.

The other error that arises from optimism has been labeled estimation error. Estimation error involves a failure to accurately appraise the time and resources needed to complete a piece of work. In one study of estimation error, Josephs and Hahn (1995) asked undergraduates the amount of time they would need to complete various academic tasks, They found that undergraduates consistently underestimated the amount of time they actually needed to complete these tasks. In a think aloud study examining undergraduates' plans for completing academic tasks, Buehler, Griffin, and Ross (1997) found that estimation errors arose from failure to consider the various impediments likely to arise once people began work. Because the development and implementation of new ideas typically presents a number of problems and impediments (Wentorf, 1992), estimation errors, while potentially useful with regard to motivation, will make it more difficult for people to manage their time and resources — effects that can make solution generation and solution implementation far more difficult than need be the case.

DISCUSSION

Before turning to some of the broader implications of our observations with regard to errors in peoples' creative problem-solving, certain limitations inherent in the present effort should be noted. To begin, we have, in the present study, focused on errors attributable to the *individual's* problem-solving activities. Thus, errors attributable to social interactional phenomena, for example group think, conformity pressures, and social loafing (e.g., Diehl & Strobe, 1991; Guastello, 1998; Price, 1985), have not been examined. Although socially induced errors may be of some importance in understanding creative performance, especially idea implementation in social settings, this topic is beyond the scope of the present effort.

Along related lines, it should be recognized that our concern in the present effort was errors in *creative* problem-solving. As a result, no attempt was made to provide herein a comprehensive treatment of errors in performance and problem-solving in general (e.g., Hogarth, 1980; Kahneman & Tversky, 1974; Reason, 1990). Instead, we have examined errors in relation to the current literature on creative problem-solving. This restriction is of some importance because certain types of creative errors, for example errors attributable to basic memory processes (Bink & Marsh, 2000), that might have noteworthy *indirect* effects on peoples' creative problem-solving activities, were not examined.

Even bearing these limitations in mind, we believe that our observations have a number of implications for understanding performance on creative problem-solving tasks. Perhaps the most clear-cut conclusion that can be drawn from the present effort is that there is reason to expect that errors occur in peoples' creative problem-solving efforts. These errors, moreover, appear to arise from certain unique characteristics of creative problems as well as the processes (Ward, Smith, & Finke, 1999) and knowledge structures (Weisberg, 1999) people apply in creative problem-solving. In a sense, this conclusion is not especially surprising given the fact that errors are commonly observed in other forms of complex cognition such as planning (Mumford, Schultz, & Osburn, 2001) and decision making (Winkler, 1977). By the same token, however, our observations indicate that the role of errors in shaping creative performance has not, at least in recent years (Gibson & McGarvey, 1937), received the attention warranted.

Table 1 presents the various errors identified in the course of this review along with the creative problem solving processes most likely to be effected by these errors. Overall, 35 errors were identified with multiple errors representing potential influences on effective execution of all of the processing activities held to be involved in creative thought. As a result, it appears that cognitive errors may represent a powerful, and pervasive, influence on the success of peoples' creative problem-solving efforts.

The errors presented in Table 1 also provides some clues about the major sources of error in creative problem-solving. Broadly speaking, these errors seem to reflect the operation of five underlying mechanisms. To begin, errors such as

TABLE 1. Summary of errors influencing creative thought

Error Type	Nature of Error	Processes Effected
1) Satisficing	Applying the most readily available, but not necessarily the most appropriate representation of the situation as the basis for structuring problem-solving activities.	Problem construction
2) Surface evaluation	Overt similarities with past experience lead people to discount unique aspects of the situation that would call for the generation of new ideas.	Problem construction Idea evaluation
3) A priori framing	Problems identified and defined to fit with, or be consistent with, extant models of the phenomenon the individual is familiar with or to which they are committed.	Problem construction
4) Premature case application	Common frequently encountered case models applied as a basis for defining and structuring the problem even if they do not capture critical unique features of the problem at hand.	Problem construction
5) Information discounting	Critical information not consistent with pre-existing assumptions, or goals at hand, tends to be ignored.	Information gathering
6) Discounting of anomalies	Information that does not readily fit with other available information is discounted.	Information gathering
7) Information availability	Over-reliance on information obtained at a relatively low cost.	Information gathering
8) Over-emphasis on tangible facts	Greater weight given to objective information rather than information implying relationships.	Information gathering Concept selection
9) Information salience	Emotionally evocative, goal relevant, information given undue weight.	Information gathering
10) Restricted information search	Information sought, and applied, only if consistent with extant models of the phenomenon.	Information gathering

TABLE 1. (continued) Summary of errors influencing creative thought

Error Type	Nature of Error	Processes Effected
11) Information accessibility	Frequently used, or recently used, information interferes with the search for, or retrieval of, other relevant information.	Information gathering Problem construction
12) Failure to explore unique causal relationships	Applies available causal concepts, or mental models, rather than identifying causal concepts, or mental models, critical to the problem at hand.	Concept selection
13) Failure to explore complex causal relationships	Focuses on simple causes, and causes linearly related to the phenomenon rather than multiple causes with complex, non-linear, non-positive relationships.	Concept selection
14) Discounting alternative models	Familiarity with, investment in, and commitment to, extant models leads people to discount alternative models and associated concepts.	Concept selection
15) Over-extended search	Over-extended search for information and concepts limits capacity for organizing information and integrating concepts.	Conceptual combination Idea generation
16) Preservation of relationships	Maintains relationships commonly observed in other relevant phenomena although they may not be relevant to the problem at hand.	Conceptual combination Idea generation
17) Illusory correlation	Assumes unobserved features of exemplars are present if they are encountered in other relevant exemplars.	Conceptual combination Idea generation
18) Concept over-determination	Emergent features discounted in conceptual combination due to over-determination of concepts attributable to a large number of familiar exemplars	Conceptual combination Idea generation
19) Concept over-differentiation	Over-differentiation of concepts restricts effective integration of unique information.	Conceptual combination

TABLE 1. (continued) Summary of errors influencing creative thought

Error Type	Nature of Error	Processes Effected
20) Inclusion of tangential concepts	Inclusion of loosely linked or "distant" concepts makes conceptual combination more difficult and is less likely to result in useful emergent features.	Conceptual combination Idea generation
21) Isolation	Problem broken into multiple small pieces that inhibit identification of critical relationships and emergence of new features.	Conceptual combination Idea generation Idea evaluation Implementation planning
22) Limited elaboration	New combinations not extended or elaborated sufficiently to allow generation of viable new ideas.	Idea generation
23) Fixing	Variable elements in the problem situation removed by assuming they are fixed thereby limiting exploration of ideas.	Idea generation Idea evaluation Implementation planning
24) Goal fixation	Ideas constructed and refined with respect to given, rather than emergent, goals.	Idea generation Idea evaluation Implementation planning
25) Functional fixedness	Traditional uses of objects or concepts limit consideration of alternative applications.	Idea generation Idea evaluation
26) Means-end analysis	Working backward from a preordained solution.	Idea generation Conceptual combination Information gathering
27) Anchoring	Initial models, or ideas, adjusted to slowly given available information.	Idea evaluation Idea generation Implementation planning

TABLE 1. (continued) Summary of errors influencing creative thought

Error Type	Nature of Error	Processes Effected
28) Insufficient idea analysis	Ideas and potential flaws in initial ideas not examined in sufficient detail to permit adequate refinement.	Idea evaluation Implementation planning
29) Rejection of risk	Ideas of high originality are untried and the risk attached to their novelty may lead to premature rejection.	Idea evaluation
30) Aversion to regret	People will reject or fail to pursue ideas, however viable, where there are overt social consequences for failure.	Idea evaluation Implementation planning
31) Over-optimism	Overly optimistic assumptions about the value, or likely success, of a new idea, inhibits refinement and development.	Idea evaluation Implementation planning
32) Over-analysis	Extensive highly detailed evaluations of new ideas limits intuitive analysis, refinement, and opportunistic trials.	Idea evaluation Implementation planning
33) Failure to commit	Failure to commit to the potential promise of an idea limits revision and inhibits initial implementation.	Idea evaluation Implementation planning
34) Confirmatory bias	Tendency to selectivity search for information confirming the value of new ideas.	Idea evaluation Implementation planning Monitoring
35) Estimation error	Consistent underestimation of the time and resources needed for effective development of a new idea.	Idea evaluation Implementation planning Monitoring

satisficing, limited elaboration, and information availability appear to arise from capacity limitations. The influence of capacity limitations on creative problem-solving, however, is not especially surprising given the processing demands that characterize most creative problem-solving efforts.

Capacity limitations, however, are not the only, or necessarily the most important, influence on creative thought. Many errors arise from an over-reliance on extant expertise. However necessary expertise is for creative thought (Weisberg, 1999), the commitment of people to extant knowledge, and their reliance on this knowledge, can inhibit creative thought. In fact, errors such as failure to explore unique causal relationships, information discounting, preservation of relationships, and concept over-determination all illustrate these negative effects of expertise.

Another theme that emerged in examining the nature of these errors involved the management of complexity through the use of simplification strategies. Some of these simplification errors, for example anchoring and means-end analysis, reflect the operation of commonly applied simplification strategies (Hogarth, 1980). Other simplification strategies, for example isolation, fixing, and overemphasis on tangible facts, represent simplification strategies, unique to creative thought.

By the same token, however, it should be recognized that errors can also arise from over -complication. Over-complication errors include not only an unduly extended search for information but also concept over-differentiation, inclusion of tangential concepts, and over analysis of idea implications. These errors, of course, arise, in part, as a result of peoples' involvement in, and commitment to, creative problem-solving efforts.

The final theme that emerged in our examination of error in creative thought involved peoples' reactions to the implications of new ideas. These reaction errors could involve errors associated with risk minimization — for example rejection of risk and failure to commit. Peoples' reactions to creative ideas, however, can also induce errors of optimism — for example estimation error and over-optimism about the likely success of a new idea.

These five mechanisms, capacity, expertise commitment, simplification, over- complication, and idea reactions, generate a number of potential errors in creative thought. Given the number of errors generated by the operation of these five mechanisms, there is a need for research examining the relative importance of the different errors arising from these five mechanisms in shaping creative thought. For example, it would be useful to know whether over-complication errors, such as concept over-differentiation, exert more powerful effects on creative thought than simplification errors, such as isolation and fixing. Moreover, there is a need for studies examining the conditions, for example stress and collegial interaction, likely to promote or inhibit certain types of errors.

Although there might be value in studies along these lines, one must ask whether methods are available that would allow us to conduct these studies. Indeed, given the many complexities and ambiguities of creative thought, it is, at first glance, difficult to see how we can study error in creative problem-solving. The various studies examined in the present review, however, illustrate a number of potentially useful approaches for the study of error in creative problem-solving. For example, one might examine the characteristics of normative, non-original creative problem solutions (Finke, Ward, & Smith, 1992). One might assess the heuristics, or strategies, used in process execution and attempt to identify those strategies associated with the production of low quality, less original ideas (Mumford, Supinski, Baughman, Costanza, & Threlfall, 1997). One might construct creative problem-solving tasks with a predefined range of viable solutions and examine reasons for departures from these optimal solution paths (Duncker, 1995; Maier & Janzen, 1969). Finally, one might apply think aloud procedures to identify the processing strategies linked to subsequent error (Buehler, Griffin, and Ross, 1997; Hershey, Read, Walsh, & Chulef, 1990). While other methods might be devised, these examples seem sufficient to make the point that methods are available for studying errors in creative problem-solving.

Of course, studies of the sort described above may not be easy to conduct. Thus, one might ask whether there is reason to study error in creative problem-solving. We would argue that, for both substantive and practical reasons, there is more than adequate justification for further research along these lines.

With regard to theory development studies of peoples' errors in creative problem-solving might allow us to extend two critical lines of inquiry. First, error analysis might tell us a great deal about the cognitive mechanisms involved in creative problem-solving. For example, the fact that errors attributable to illusory correlation are observed in creative problem-solving points to the importance of schema or categorical knowledge structures (Ward, 1994). The fact that causal assumptions can lead to errors suggests that it might be important to understand the mental models people bring to creative problem-solving tasks (Carlson & Gorman, 1992).

On a more practical level, error analysis might tell us something about the conditions likely to promote creative thought. If people err due to the application of extant models, then structuring the conditions of task performance to insure that alternative models will be considered is likely to prove of value (Schwenk & Crozier, 1980). Alternatively, if people err due to capacity limitations then one might reduce extraneous demands when people are working on creative problem-solving tasks.

These observations about the conditions associated with error in peoples' creative problem-solving activities are noteworthy, in part, because they suggest that by understanding error we may be able to improve peoples' performance in creative problem-solving. Although simply familiarizing people with common errors is unlikely to have much impact on their performance (Mumford, Schultz, & Van Doorn, 2001), training people in various error management strategies may prove of substantially greater value (Woods & Davies, 1973). Indeed, the conclusions drawn in the course of this review suggest a number of techniques that might be of value — techniques ranging from the identification of negative consequences to extension of representational search and the analysis of underlying assumptions.

Although there is reason to suspect that interventions of the sort described above might prove useful, the development of these kinds of interventions requires a better understanding of the role of error in creative problem-solving. Hopefully, the present effort, by identifying some likely sources of error, will provide a foundation for future research along these lines.

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