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Cognitive Abilities Involved in Insight Problem Solving: An Individual Differences Model

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This study investigated individual differences in cognitive abilities that contribute to solving insight problems. A model is proposed describing three types of cognitive ability that contribute independently to insight: convergent thinking, divergent thinking, and breaking frame. The model was tested in a large sample ($N = 108$) by regressing insight problem solving performance on measures of these three abilities. This analysis demonstrated that all three abilities predicted insight independently. Convergent thinking was further broken down into verbal intelligence and working memory, which also predicted insight independently of each other and of divergent thinking and breaking frame. Finally, when pitted against noninsight problem solving as a predictor in regression, only insight problem solving was uniquely associated with divergent thinking and breaking frame. The model is suggested as a potentially useful taxonomy for the study of ill-defined problems and cognitive abilities.

PROBLEM SOLVING AND PROBLEM FORMULATION

A *problem* may be defined as a situation in which one's current state differs from some goal state, and in which there is some uncertainty as to whether or how the goal can be achieved, within any relevant constraints, such as time (Duncker, 1945; Holyoak, 1995; Newell & Simon, 1972; Peterson, 1999). The manner in which an individual conceives or frames a problem has been referred to as the *problem formulation*, which, in addition to the current state, goal state, and constraints, includes a set of available operators—procedures that may be used in the attempt to transform the current state into the goal state (Newell & Simon, 1972). Human beings have been described as fundamentally goal-directed, constantly guided by the need to reduce differences between their current states and their goal states (Carver & Scheier, 1998; Peterson, 1999). Further, human existence is inherently imited, and uncertainty is a basic and continual feature of life (Peterson, 1999; Peterson & Flanders, 2002), implying that problem solving could be considered a central task of human existence and thus of the mind/brain.

Problems may be divided into two general classes: well-defined and ill-defined (Getzels, 1975; Pretz, Naples, & Sternberg, 2003; Voss & Post, 1988). In a well-defined problem, the correct formulation is given—that is, the problem is presented with the expectation

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that the current state, goal state, and operators will be sufficiently obvious to allow steady (if not certain) progress toward the goal. If progress cannot be made, this should be due to a lack of relevant knowledge or skill, rather than to some inadequacy in the problem formulation. Most problems used in educational and psychological testing are well-defined. Most problems in life, however, are ill-defined (Brooks, 1991; Voss & Post, 1988). In an ill-defined problem, uncertainty inheres not only in whether the goal will be reached but in how best to conceive the current state, goal state, and/or or operators. The real problem, therefore, is how to develop a new problem formulation, transforming the ill-defined problem into a well-defined problem that can be solved. Imagine instructing a student simply to "write a good, one-page essay." This would be an ill-defined problem, and the student would undoubtedly ask about the desired content and form of the essay in an attempt to transform it into a well-defined problem. Often, however, one can rely on no one but oneself to reformulate a problem.

The skill of effective problem formulation William James (1890) labeled *sagacity*. In discussing creativity, Einstein noted that "[t]he mere formulation of a problem is far more often essential than its solution" (Einstein & Infeld, 1938, p. 83). What makes sagacity both essential and difficult to achieve? The major complication, when generating a problem formulation, is to determine what aspects of the situation are relevant. Unfortunately, the amount of information available in any situation is vast, relative to our limited capacity for modeling, and it appears that no objective criteria can be specified to determine which aspects of a situation are relevant to any given goal (Brooks, 1991; Medin & Aguilar, 1999; Peterson & Flanders, 2002). Considerable attention has been directed, in psychological research on reasoning and intelligence, toward understanding how people solve well-defined problems. But how is a problem formulation established in the first place? How do people solve ill-defined problems? What underlies sagacity and creative thinking? These important questions may be approached empirically through a type of formal ill-defined problem known as insight problems (cf. Lockhart, Lamon, & Gick, 1988).

Insight and Insight Problems

Ill-defined problems usually become apparent as such when the way in which one is approaching some goal proves inadequate and when all other readily conceived strategies (the available operators) also prove inadequate. Thus, an impasse is reached. To continue moving forward, one must then restructure the problem formulation, meaning that the way in which the problem's starting state, goal state, and/or operators are conceived must be changed in some way. The term *insight* typically indicates the moment when a new, more effective formulation appears in mind, "enabl[ing] the subject to view the given situation in a new and more penetrating perspective" (Wertheimer, 1945, 1959, p. 169), and thereby overcoming the impasse. *Insight problems* are those problems that require restructuring for their solution. Formal insight problems used in laboratory investigations possess multiple specifically identifiable formulations. Additionally, the formulation that is strongly dominant for most people, on first encounter, is incorrect and leads to an impasse. The multiple-marriage problem, for example (Table 1, problem 2), leads people to interpret the word *married* in its more common sense, rendering the problem impossible to solve. Insight requires the realization that marrying can be an activity undertaken by priests, as well as grooms. This sort of problem is obviously different from well-defined problems in which the correct formulation is given at the outset. In the literature on insight, well-defined problems are typically referred to as *standard*, *analytic*, or *noninsight problems* because they do not require restructuring.

How restructuring takes place is one of the central questions in research on insight, and a variety of different processes are hypothetically involved, such as selective encoding, selective recombination, and selective comparison (Davidson, 2003), chunk decomposition and constraint relaxation (Knoblich, Ohlsson, Heider, & Rhenius, 1999), or recognition of invariants in failed solution attempts (Kaplan & Simon, 1990). Compelling evidence has been presented for each of these, and it seems clear that different insight problems are amenable to different processes of restructuring. Another central question is more general: What broad cognitive abilities support insight? The present study attempted to address this question using an individual differences approach, which relies on the principle that, if a certain cognitive ability is involved in the production of insight, then performance on a measure of this ability should be predictive of insight problem-solving performance (Schooler & Melcher, 1995).

Relatively few studies of individual differences in insight have, thus far, been reported, but two patterns are nonetheless emerging (Ansburg, 2000; Ash & Wiley, 2006; Baker-Sennet & Ceci, 1996; Davidson, 1986; Davidson & Sternberg, 1986; Jacobs & Dominowski, 1981; Schooler & Melcher, 1995). First, performance on well-defined problems, including those that make up standard IQ tests, is associated with performance on insight problems (Davidson, 2003; Schooler & Melcher, 1995). Thus, people who are more intelligent, in the standard sense, also tend to be more insightful. Second, insight is associated with a set of interrelated abilities that involve using loose or remote associations, analogies, and pattern recognition (Ansburg, 2000;

TABLE 1
Insight Problems and Their Solution Rates

Insight Problems (with Answers)	*Solution Rate %*
1. An unemployed woman did not have her driver's license with her. She failed to stop at a railroad crossing, then ignored a one-way traffic sign and traveled three blocks in the wrong direction down the one-way street. All this was observed by a policeman, who was on duty, yet he made no effort to arrest the woman. Why? *She was not driving; she was walking/a pedestrian.*	59
2. A man in a town married 20 women. He and the women are still alive, and he has had no divorces or annulments. He is not a bigamist (meaning he is not legally married to more than one woman at once), and he broke no law. How is that possible? *He is a priest or justice of the peace.*	32
3. Two men played five full games of checkers and each won an even number of games, with no ties, draws, or forfeits. How is that possible? *They were not playing against each other.*	54
4. A young boy turned off the lights in his bedroom and managed to get into bed before the room was dark. If the bed is ten feet from the light switch and the light bulb and he used no wires, strings, or other contraptions to turn off the light, how did he do it? *It was still daylight/Light was still coming in from outside.*	30
5. A giant inverted steel pyramid is perfectly balanced on its point. Any movement of the pyramid will cause it to topple over. Underneath the point of the pyramid is a $100 bill. How could you remove the bill without disturbing the pyramid? *Tear, cut, or burn the bill.*	24
6. Professor Bumble, who is getting on in years, was driving along in his old car when suddenly it shifted gears by itself. He paid no attention and kept on driving. Why wasn't he concerned? *The car had automatic transmission.*	53
7. Mr. Hardy was washing windows on a high-rise office building when he slipped and fell off a sixty foot ladder onto the concrete sidewalk below. Incredibly, he did not injure himself in any way. How is this possible? *He was on one of the lower rungs of the ladder.*	53
8. There is an ancient invention still used in many parts of the world today that allows people to see through walls. What is it? *Glass/windows.*	75
9. Our basketball team won 72–49, and yet not one man scored as much as a single point. How is that possible? *It was a women's or coed basketball team.*	44

Baker-Sennett & Ceci, 1996; Jacobs & Dominowski, 1981; Schooler & Melcher, 1995).

The fact that insight problem solving is associated with standard analytic problem solving and IQ indicates that it may involve some of the same processes. This does not mean that insight cannot usefully be distinguished from standard intelligence (as insight may require additional processes not shared with standard problem solving and IQ), but it does raise a problem for the individual differences approach, which has not been adequately addressed. Demonstrating that insight problems are genuinely distinct from noninsight problems has been an important concern in insight research, largely because of claims to the contrary (e.g., Chronicle, MacGregor, & Ormerod, 2004; Weisberg & Alba, 1981). Experimental comparisons have shown that the suddenness with which path to solution is realized, the ineffability of cognitive processes leading to solution, and the tendency of verbalization to hinder problem solving are all characteristic of insight problems but not of standard analytic problems (Metcalfe & Weibe, 1987; Schooler & Melcher, 1995; Schooler, Ohlsson, & Brooks, 1993). These demonstrations of discriminant validity suggest real underlying distinctions. In research on individual differences, however, determination of which abilities contribute uniquely to insight has been hindered by failure to control adequately for the association between insight problem solving and standard intelligence or analytic problem solving.[1] What is needed is to determine what abilities are associated with insight, independently of the ability to solve well-defined problems.

Three Types of Cognitive Ability Involved in Insight

Consideration of the differences between well- and ill-defined problems and of the difficulty of generating effective problem formulations led to a model specifying

[1]Schooler and Melcher (1995) attempted to address this concern by showing that certain tasks predicted performance on insight problems but not noninsight problems and found, for example, that the ability to identify out-of-focus pictures (a form of pattern recognition) was significantly correlated with insight ($r = .45$, $p < .01$) but not with analytic problem solving ($r = .21$, $p > .05$). However, the difference in significance alone cannot lead to a strong conclusion because a test for the equality of these correlations (Steiger, 1980) indicates that they are not significantly different from each other ($t_{(48)} = 1.63$, $p = .11$). Additionally, insight and analytic problem solving were significantly correlated in their sample ($r = .36$, $p < .05$). Given the effect sizes, it seems likely that pattern recognition is a unique contributor to insight, but the possibility that they are related because both share variance with analytic problem solving should be ruled out through partial correlation or regression.

three types of cognitive ability that contribute to restructuring and insight. Operation within a particular problem formulation requires efficient logical application of available operators, bearing in mind relevant constraints; this is equivalent to solving well-defined problems. Operation without a specific problem formulation—in other words, attempting to generate a novel formulation—appears to require the ability to access a wide range of associated or analogous information and recognize relevant patterns. Cognitive abilities characteristic of the first mode appear linear, logical, and analytical—and highly similar, if not identical, to standard intelligence or IQ. Those cognitive abilities characteristic of the second, by contrast, appear more loosely associative, nonlinear, and holistic. The existence of these nonlinear, holistic cognitive functions, as distinct from linear, logical thought, was posited by the Gestalt school (Duncker, 1945; Maier, 1931; Wertheimer, 1945, 1959), who first noted their relevance to insight. The two types of ability map reasonably well onto Guilford's (1950) classic distinction between *convergent* and *divergent* thinking. Convergent thinking moves linearly and logically toward a single solution, whereas divergent thinking moves associatively through a web of related ideas or images.[2] Schooler and colleagues (1995) drew a similar distinction, using the terms *reasoning* and *pattern recognition*.

Although the type of cognitive ability characterized by divergent thinking and pattern recognition has usually been emphasized in theory as the key contributor to insight (e.g., Ansburg, 2000; Duncker, 1945; Fiore & Schooler, 1998; Schooler & Melcher, 1995), the association of insight with standard intelligence or convergent thinking should not be overlooked. Nor is it surprising, theoretically, that both convergent and divergent thinking should foster insight. Restructuring should require convergent logical analysis to help determine the inadequacy of the initial formulation and to verify or falsify new formulations as they are generated. Once a flawed formulation has been abandoned, restructuring should require divergent thinking to discover the elements and structure of new formulations. The two are complementary, and divergent processes seem likely to be necessary but not sufficient to produce insight (Fiore & Schooler, 1998).

Even together, however, convergent and divergent thinking do not appear sufficient to encompass all of the abilities that might contribute to insight. During problem solving, logical analysis may help to determine the inadequacy of the current frame, but it is extremely unlikely to provide indubitable proof of this inadequacy, as some untried combination of operators is always likely to remain, due to the exponentially large number of possible combinations in any nontrivial problem (Newell & Simon, 1972). Something else must determine when an impasse will lead to abandoning the initial formulation and searching for a new one. A distinct ability to *break frame* may allow for transitions between convergent and divergent thinking. This argument suggests the hypothesis that a measure of the ability to break frame might contribute to the prediction of insight independently of both convergent and divergent thinking.

Despite the fact that processes of frame-breaking—described as overcoming "fixation" (Maier, 1931), "functional fixedness" (Duncker, 1945), or "context-induced set" (Schooler & Melcher, 1995)—have long been associated with insight, there are few good specific measures of such processes.[3] (Insight problems themselves obviously require breaking frame, but they are not *specific* in assessing this ability, given that other abilities appear to aid in their solution as well.) To measure the ability to break frame, we employed Bruner and Postman's (1949) anomalous card identification task, in which participants describe playing cards presented for very short durations (Peterson, Driver-Linn, & DeYoung, 2002). After describing a number of normal cards, participants are presented with an anomalous card (a black four of hearts). All cards are presented again and again at longer and longer durations, until they are correctly identified. Bruner and Postman (1949) employed the task simply to demonstrate that humans have comparative difficulty categorizing anomalous stimuli, and, indeed, it took many more trials for participants to identify the anomalous card than to identify the

[2]We employ these terms as convenient labels, recognizing that they may not in every instance fit Guilford's (1950) original use of these terms exactly. For example, Guilford specified that convergent tasks would have a single correct solution, whereas divergent tasks would have many correct solutions. However, tasks that tap divergent thinking, in the broad sense that we are employing, may require a single solution that must, however, be reached by searching divergently through many associations in memory and recognizing a pattern. Identification of blurry pictures (Schooler & Melcher, 1995) and the remote associates test (Bowden & Beeman, 1998, 2003), in which a single word must be found that is associated semantically with three other words (e.g., cue: *house, apple, winter*; target: *green*), are good examples. Our usage emphasizes process over outcome.

[3]Schooler and Melcher (1995) proposed two measures of the ability to break context-induced set, but neither seems adequate: (a) the Group Embedded Figures Test (GEFT), and (b) the extent to which viewing an extremely out-of-focus picture interferes with subsequently identifying the same picture when it is somewhat less out-of-focus. The GEFT was designed as a measure of field independence (Witkin, Oltman, Raskin, & Karp, 1971), and, although picking a pattern out of a noisy background may be a good measure of pattern recognition or the ability to ignore distracters, it does not seem necessary to assume that participants formulated an initial frame or set that needed to be overcome to complete the task. Similarly, it is hard to be certain that the interference produced by extremely out-of-focus pictures is the result of the formation of an initial frame (nor was this interference found to be associated with insight; Schooler & Melcher, 1995).

normal cards. However, the task may also be used as a measure of individual differences, with the ability to break frame indicated by the number of trials prior to identification of the anomalous card (Peterson et al., 2002). Faced with the anomalous card, many participants err at first by preserving color and labeling it "four of spades" or by preserving shape and labeling it "four of hearts." Despite being told to describe exactly what they see, participants formulate the problem as one of identifying normal playing cards, and then have difficulty breaking frame to accommodate an anomaly. Because the task requires only the description of a simple visual stimulus, it seems unlikely that much thinking, convergent or divergent, is involved. Nonetheless, many participants remain stuck in their initial frame for a surprisingly large number of trials. One of our participants summed up the difficulty of breaking frame by exclaiming, after several incorrect descriptions of the anomalous card, "It looks like a black four of hearts. But that's impossible!"

Testing the Model

If the model presented above is accurate, convergent thinking, divergent thinking, and breaking frame each contribute something unique to insight problem solving. This hypothesis was tested by administering a battery of insight problems, plus the anomalous card task and measures of divergent thinking and standard intelligence (convergent thinking), then using regression to determine whether the latter three tasks predicted insight independently.

Additionally, working memory was assessed and the measure of intelligence was broken down into indices of verbal intelligence and analytic problem-solving ability. These additional measures allowed two further analyses. First, the role of verbal or crystallized intelligence in insight could be tested and contrasted with the role of working memory, which is strongly linked to fluid intelligence (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002). This analysis allowed a more fine-grained investigation of the link between intelligence and insight.

We hypothesized that verbal intelligence and working memory would contribute independently to insight. Verbal intelligence, which has been described as "crystallized" rather than "fluid" due to its reliance on acquired knowledge, may be particularly relevant for solving insight problems presented exclusively in words (as opposed to geometric or object-use problems). Insight problems have not typically been considered to require previously acquired knowledge, but some research indicates that insight is facilitated by experience with various types of creative problem solving (Martinsen, 1993, 1995), and acquired verbal ability might be similarly helpful for problems presented in words.

In contrast, working memory (the ability to monitor and manipulate information in short-term memory) appears to be a central component of fluid intelligence, the ability to solve novel problems for which prior knowledge is not relevant. Structural models incorporating working memory tasks and traditional measures of fluid intelligence have demonstrated that the two constructs are very strongly related (Conway et al., 2002; Kyllonen, 1996), and neuroimaging has revealed that tasks requiring working memory and fluid intelligence activate the same brain regions (Duncan et al., 2000; Gray, Chabris, & Braver, 2003). A recent study found that working memory was positively associated with insight problem solving, but only when there was a large faulty search space prior to restructuring (Ash & Wiley, 2006). This finding is consistent with the hypothesis that convergent thinking processes, such as working memory, are important for determining the inadequacy of the initial problem formulation, prior to restructuring.

Finally, breaking down intelligence into verbal intelligence and analytic problem-solving ability meant that insight problems could be pitted against the sort of analytic problems with which they have typically been compared (e.g., Metcalfe & Weibe, 1987; Schooler & Melcher, 1995), allowing a test of discriminant validity for insight and noninsight problem solving. The two types of problem solving were compared as simultaneous predictors of the other cognitive variables, thereby testing the hypothesis that divergent thinking and breaking frame are uniquely associated with insight but not noninsight problem solving.

The various constructs described by the model and the relations among them posited by the above hypotheses are depicted in Figure 1. Here the multiplicity of

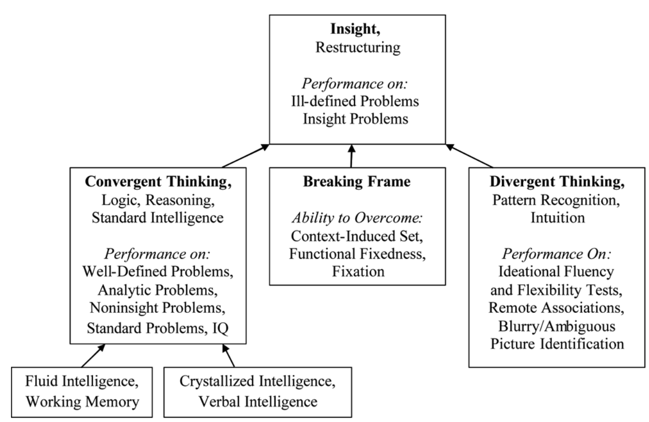

FIGURE 1 Summarizes the model indicating relations among constructs relevant to insight problem solving. Terms within each box are here treated as practically equivalent, although theoretical and empirical distinctions can be made among them in other contexts. Arrows indicate the contributions of more specific abilities to more general abilities.

existing terminologies are brought together to allow translation and enhance clarity. Arrows indicate the contributions of more specific cognitive abilities to more general ones. Note that insight or restructuring is considered the most general type of cognitive ability because it is hypothesized to be supported by all the others.

METHOD

Participants

Participants in this study were 108 undergraduates (26 men, 82 women) in a first-year psychology course at the University of Toronto, who completed the experiment for course credit. Additional demographic information on these participants is not available, but a different sample from this same course ($N = 279$) ranged in age from 17 to 30 years, with a mean of 18.80 ($SD = 1.93$; DeYoung, Hasher, Djikic, Criger, & Peterson, 2007); the present sample should be very similar.

Insight Problems

Nine insight problems (Table 1) were used, all of which could be determined as *pure*, based on the taxonomy proposed by Weisberg (1995), who noted that some of the inconsistencies in the insight literature may be due to the use of problems that do not necessarily require restructuring for their solution. His taxonomy identifies three general categories of problem: (a) well-defined problems in which no restructuring is needed to solve the problem, although there may be discontinuities in the problem solving process due to mistakes in the application of operators or to arrival at incorrect solutions or dead ends prior to the correct solution (e.g., a long-division problem, anagram, or maze); (b) hybrid problems, in which restructuring could achieve solution, but other processes, such as trial-and-error, might also be successful (e.g., the commonly used 9-dot problem; Kershaw & Ohlsson, 2004; Weisberg & Alba, 1981; or the coin manipulation problems used by Chronicle et al., 2004); (c) pure insight problems, which can only be solved by restructuring and which require nothing more than restructuring because the solution is immediately apparent once the proper formulation is achieved. This taxonomy guided the selection of pure insight problems that initially lead the majority of people to an incorrect formulation and consequent impasse, and which have no possibility of trial-and-error solution. These problems were collected from published research on insight, with slight modifications to minimize confusion or eliminate possible correct but noninsightful solutions. Problems were chosen to cover a range of difficulty, attempting to ensure that insight problem solving performance would be a normally distributed variable. All of these problems were verbal because of the difficulty of constructing nonverbal insight problems that are not hybrid (usually due to the possibility of trial-and-error progress toward solution). Pure insight problems were preferred to allow confidence that predictors of performance were not associated with variance in processes other than insight. Admittedly, this strategy limits generalization to insight problems in nonverbal modalities. Hopefully, future research will address this concern.

Problems were presented in random order, and participants were given 2 min to solve each problem. This duration was chosen because Lockhart and colleagues (1988), who gave participants 4 min to solve similar insight problems, reported that 97% of solutions were generated in the first 2 min. Participants were instructed to write "familiar" after answers to any of the problems with which they had previous experience, and performance scores were calculated as percentage correct on unfamiliar problems (13 participants were familiar with one of the problems, and 5 participants were familiar with two).

Divergent Thinking

Three of the Torrance Tests of Creative Thinking (Torrance, 1974) were used to assess divergent thinking. Participants were given 3 min to generate as many possible answers as they could for each of the following problems: (a) "Suppose that all humans were born with six fingers on each hand instead of five. List all the consequences or implications that you can think of;" (b) "List as many white, edible things as you can;" (c) "List all the uses you can think of for a brick." Divergent thinking scores are based on three indices: fluency, originality, and flexibility. Fluency is the total number of responses given. Originality is scored with reference to all valid responses in the sample, with one point being awarded to responses given by between 3% and 10% of respondents, two points to responses given by 3% or fewer, and three points to unique responses. Flexibility is the number of times participants switch categories as they list answers (categories for problem 2, for example, included fruits, vegetables, meat, dairy, baked goods, seafood, and other). These three indices can be examined separately, or standardized and combined into a single divergent thinking score. One participant did not complete the divergent thinking measure.

Convergent Thinking

The Wonderlic Personnel Test (WPT) is a short, timed test of intelligence, in which participants are given 12 min to solve as many of 50 problems as they can. These problems are all well-defined and similar to those appearing on standardized tests like the SAT. The WPT is well validated and correlates very highly ($\sim$.90) with standard IQ, as assessed by the WAIS-R (Dodrill, 1981; Hawkins, Faraone, Pepple, & Seidman, 1990; Wonderlic, 2000). In addition to using full-scale WPT scores, we categorized 27 WPT items as *verbal* because they require only judgments about the meanings of words or phrases and are heavily reliant on crystallized knowledge. The remaining 23 problems, which were word problems requiring mathematical or logical analysis, we categorized as *analytic*. Although crystallized knowledge may contribute to facility with mathematical and logical analyses, such problems also require fluid intelligence. Thus, these analytic problems are not likely to be pure measures of either crystallized or fluid intelligence. They are, however, very similar to the well-defined noninsight problems typically used for comparison with insight problems in prior research (e.g., Metcalfe & Weibe, 1987; Schooler & Melcher, 1995). Scores on the two subsets of WPT items were used as measures of verbal intelligence and analytic (noninsight) problem solving, respectively. WPT data were unavailable for four participants due to errors in adminstration (more than 12 min allowed).

Working Memory

Working memory was assessed with a self-ordered pointing task that has been widely used in the neuropsychology literature (Petrides & Milner, 1982). Participants were presented with 12 abstract stimuli arranged in a grid and instructed to use the mouse to select each stimulus exactly once. After each selection, the spatial location of all stimuli changed. Participants completed this task twice to increase score reliability. Mean number of errors across both administrations were logarithmically transformed and reversed in sign to yield a normally distributed, positive index of performance. Performance on this task is related to standard measures of fluid intelligence (DeYoung, Peterson, & Higgins, 2005) and activates the dorsolateral prefrontal cortical region associated with working memory (Petrides, Alivisatos, Evans, & Meyer, 1993). Data were unavailable for two participants due to computer malfunction, and data for two additional participants were excluded because their performance was below chance. Our prior experience with this task suggests that a score below chance indicates that the participant misunderstood instructions and attempted to identify the same stimulus (rather than a different stimulus) on each trial.

Breaking Frame

Bruner and Postman's (1949) anomalous card task was used as a measure of the ability to break frame (Peterson et al., 2002). Participants were positioned approximately 24 inches in front of a 17-inch computer monitor and asked to read the following instructions: "Once the task has begun, please focus on the cross in the center of the screen. Then describe exactly what appears on the screen. Once you are satisfied that you have provided a complete description, tell the experimenter 'ready' to move on to the next trial. Now, please tell the experimenter when you are ready to begin." After the disappearance of the fixation cross, a single playing card was presented in the center of the screen. Each trial consisted of the presentation of a card, followed by the participant's description. The experimenter recorded responses as *correct* or *incorrect*. Each card was presented in its first three trials at a duration of approximately 24 milliseconds (the shortest presentation time possible on the computers used). Duration for the next three trials was 35 milliseconds, after which duration doubled and continued to double after every three trials. Four normal cards (9 of hearts, 5 of spades, 7 of clubs, 3 of diamonds) were presented prior to the anomalous card, a black 4 of hearts. Because virtually all participants can identify the normal cards on the first or second trial (Peterson et al., 2002), the normal cards were presented between five and eight times, regardless of how quickly they were correctly identified, to eliminate any contextual cues concerning the oddity of the anomalous card. The anomalous card was presented as many times as necessary to achieve correct identification, up to a maximum of 30 trials. Score on the task was number of trials to correct identification of the anomalous card. Participants who did not identify the card correctly after 30 trials were given a score of 31. Five participants did not complete this task, due to time constraints. Four additional participants were excluded from all analyses due to unfamiliarity with playing cards, as determined in debriefing if participants described themselves as being unfamiliar with cards or did not realize that it would be unusual to have black hearts. Further questioning revealed that these four participants were from cultural backgrounds in which standard Western playing cards are not used.

Psychometric Analyses

Prior to testing our hypotheses, we examined the psychometric properties of our insight battery, the anomalous card task, and the separated WPT-Analytic and -Verbal scores. As noted by Schooler and Melcher (1995), early studies of individual differences in insight often used a single insight problem, leaving serious doubts about reliability and generalizability. With regard to the anomalous card task, we expected that the number of trials needed to identify the anomalous card might not be normally distributed, based on previous experience with the task (Peterson et al., 2002). In the WPT, the hypothesis that the analytic problems would measure a combination of verbal or crystallized intelligence and fluid intelligence or working memory was tested by regressing WPT-Analytic on WPT-Verbal and working memory.

RESULTS

Psychometrics

Solution rates for the insight problems are presented in Table 1. Insight performance was normally distributed, $M = .49$, $SD = .24$, Skewness $= -0.15$, Kurtosis $= -0.90$. Cronbach's Alpha for all nine problems was .61, indicating adequate internal reliability. Performance on the anomalous card task (CARD) was bimodally distributed (see Figure 2). CARD scores were therefore dummy-coded to create a dichotomous variable, splitting the sample at the natural break point appearing at 8 trials. This yielded a high-performance group who correctly identified the anomalous card in 7 trials or fewer (coded as 1, $N = 44$), and a low-performance group requiring 9 trials or more (coded as 0, $N = 55$). This dummy-coded variable was used for all regressions, so as not to violate the assumption of normality. (Results were very similar if the continuous scores were used.)

Analytic and verbal scores from the WPT were normally distributed, WPT-Verbal: Skewness $= -0.67$, Kurtosis $= 0.58$; WPT-Analytic: Skewness $= -0.07$, Kurtosis $= 0.36$. Alpha reliabilities were acceptable, WPT-Verbal: Alpha $= .67$: WPT-Analytic: Alpha $= .64$.

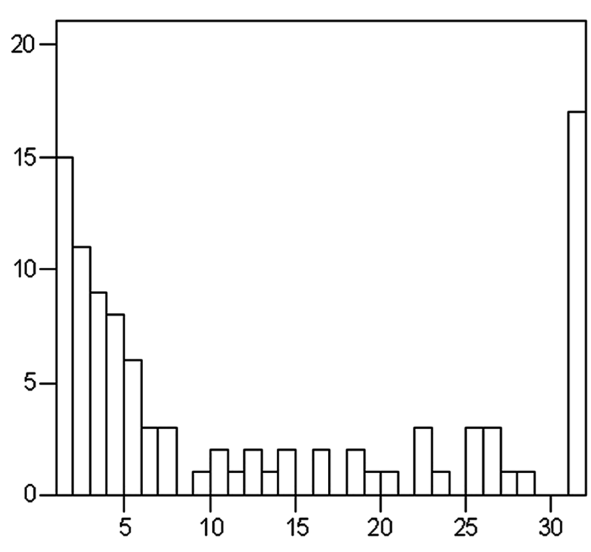

FIGURE 2 Distribution of performance on the anomalous card task.

Regression indicated that verbal intelligence (WPT-Verbal) and working memory (WM) contributed independently to analytic problem solving (WPT-Analytic), WPT-Verbal: $\beta = .36$, $p < .001$; WM: $\beta = .25$, $p < .05$, suggesting that the analytic problems do, indeed, require both crystallized and fluid intelligence. By contrast, when verbal intelligence was regressed on analytic problem solving and working memory, only analytic problem solving was a significant predictor, WPT-Analytic: $\beta = .39$, $p < .001$; WM: $\beta = .08$, $p = .42$. These regressions provide evidence of discriminant validity for the two subsets of WPT items.

Correlations

Correlations among all variables are presented in Table 2. Insight problem solving performance was significantly correlated with all cognitive variables, except for the originality index of divergent thinking.

Predictors of Insight

The differences in strength of correlation between insight and the three indices of divergent thinking suggest that it may not be ideal to use the combined divergent thinking score as a predictor of insight. As a preliminary test, insight was regressed on fluency, originality, and flexibility simultaneously. Only flexibility predicted unique variance in insight; fluency: $\beta = .16$, $p = .50$; originality: $\beta = -.29$, $p = .13$; flexibility: $\beta = .47$, $p < .01$. In all subsequent regressions, therefore, fluency was used as the index of divergent thinking. (Results remained substantively the same if the combined divergent thinking score was used, though effect sizes were slightly smaller.)

Three regressions testing independent predictors of insight are shown in Table 3. The first regression confirmed that standard intelligence (WPT-Total), divergent thinking (flexibility), and ability to break frame (CARD) all predicted insight performance independently, thus confirming our primary hypothesis. The second regression, carried out to test the hypothesis that verbal intelligence (WPT-Verbal) and working memory might represent distinct aspects of intelligence contributing to insight, confirmed that working memory, verbal intelligence, divergent thinking, and ability to break frame were all independent predictors of insight.

A third regression was used to confirm the overlap between measures of convergent thinking depicted in Figure 1. This regression demonstrated, in block one, that analytic problem solving (WPT-Analytic) could be used as a replacement for standard intelligence (WPT-Total), predicting insight independently of divergent

TABLE 2
Correlations for all Variables; Samples Sizes Appear Above the Diagonal

	INS	*FLU*	*ORIG*	*FLEX*	*DT*	*WPT*	*WPT-A*	*WPT-V*	*WM*	*CARD*
1. Insight	–	103	103	103	103	100	100	10	99	99
2. Fluency	.29**	–	103	103	103	99	99	99	98	98
3. Originality	.16	.87**	–	103	103	99	99	99	98	98
4. Flexibility	.41**	.81**	.66**	–	103	99	99	99	98	98
2. Total divergent thinking	.31**	.97**	.92**	.88**	–	99	99	99	98	98
3. WPT total score	.44**	.16	.04	.24*	.16	–	10	10	95	95
4. WPT analytic	.45**	.11	.01	.21*	.12	.77**	–	10	95	95
5. WPT verbal	.32**	.16	.06	.19†	.14	.90**	.41**	–	95	95
6. Working memory	.32**	.02	−.06	.11	.02	.32**	.32**	.20*	–	95
7. Anomalous card task	−.33**	−.18	−.04	−.17	−.14	−.20*	−.20†	−.15	−.11	–
8. CARD category	.30**	.16	.10	.12	.14	.17	.10	.15	.15	−.87**

Note. CARD Category = dichotomous scoring of anomalous card task (good performance vs. poor performance). Correlations are Pearson's *r*, except for those involving variable 7, which are Spearman's rho.
*$p < .05$; **$p < .01$; †$p < .06$ (two-tailed).

thinking and ability to break frame. In block two, when working memory and verbal intelligence were entered, they did not predict significantly over and above analytic problem solving, and the change in R^2 was not significant, $R^2_{\text{change}} = .03$, $p = .18$. The results in this second block confirmed that analytic problem solving accounts for the same variance as the combination of working memory and verbal intelligence. In Figure 1, this overlap is represented by the fact that working memory and verbal intelligence both contribute to convergent thinking, which contributes to insight problem solving.

TABLE 3
Regressions Demonstrating Independent Predictors of Insight

Predictors	*β*	*t*	*N*	*df*	*F*	R^2
Regression 1			94	3	14.77**	.33
WPT-Total	.35	3.87**				
Flexibility	.29	3.30**				
CARD	.21	2.37*				
Regression 2			90	4	9.39**	.31
WM	.19	2.07*				
WPT-Verbal	.20	2.08*				
Flexibility	.31	3.32**				
CARD	.21	2.30*				
Regression 3 (block 1)			90	3	14.99**	.34
WPT-Analytic	.36	4.04**				
Flexibility	.28	3.13**				
CARD	.24	2.75**				
Regression 3 (block 2)			90	5	9.86**	.37
WPT-Analytic	.29	2.91**				
Flexibility	.27	3.04*				
CARD	.21	2.41*				
WM	.14	1.55				
WPT-Verbal	.09	0.89				

Note. WPT, Wonderlic Personnel Test; WM, working memory; CARD, anomalous card task.
*$p < .05$; **$p < .01$ (two-tailed).

Differences Between Insight and Noninsight Problems

Finally, regressions were carried out to test the hypothesis that both divergent thinking and ability to break frame would be uniquely associated with insight but not noninsight problem solving. Insight and analytic problem solving (WPT-Analytic) were used as simultaneous predictors, to control for their shared variance. (The fact that insight is here used as a predictor, whereas in the previous analyses it was our criterion or outcome variable, does not indicate a reversal of our causal hypothesis that insight is the outcome of other more basic processes, including standard analytic problem solving. These regressions merely served the purpose of controlling for the variance shared between insight and noninsight problem solving, in order to determine their unique associations with other variables.) Binary logistic regression (used instead of linear regression because of the dichotomous CARD scores) showed that insight was significant as a unique predictor of ability to break frame (B = 2.78, S.E. = 1.03, Wald = 7.36, $p < .01$) but analytic problem solving was not (B = −0.95, S.E. = 2.71, Wald = 0.12, $p = .73$). Linear regression showed that insight was also a unique predictor of divergent thinking, but analytic problem solving was not (Table 4). In contrast, both analytic problem solving and insight predicted working memory and verbal intelligence (though insight predicted verbal intelligence only at a trend level of significance).

DISCUSSION

Most problems in life are ill-defined rather than well-defined, but relatively little is understood about the processes and abilities that support the solution of ill-defined problems. Because insight problems are formal

TABLE 4
Linear Regressions Demonstrating Associations of Insight and Analytic Problem Solving with Other Cognitive Variables

Criterion Variable	*Predictors*	β	t	p	N	df	F	R^2
Flexibility					99	2	9.17**	.16
	Insight	.38	3.63	.00				
	WPT-Analytic	.04	0.41	.69				
WM					95	2	7.59**	.14
	Insight	.23	2.08	.04				
	WPT-Analytic	.22	1.98	.05				
WPT-Verbal					100	2	11.53**	.19
	Insight	.17	1.70	.09				
	WPT-Analytic	.33	3.27	.00				

Note. WPT, Wonderlic Personnel Test; WM, working memory. See text for binary logistic regression of the anomalous card task on insight and analytic problem solving.
$^{**}p < .01$.

ill-defined problems, the present study investigated the cognitive abilities that support insight problem solving. A model was tested specifying three types of cognitive ability that underlie insight: (a) convergent thinking (linear, logical, analytical); (b) divergent thinking (non-linear, associative, holistic); and (c) ability to break frame (simliar to breaking out of functional fixedness; Duncker, 1945). A series of regressions confirmed that measures of constructs representative of these three types each contributed independently to insight problem solving. The independence of the contributions of the three predictors is of key importance. One would not be surprised to find simply that various measures of cognitive ability were related to each other. Rather, what is notable is that convergent thinking, divergent thinking, and ability to break frame each predicted unique variance in insight problem solving. Rather than merely showing that people with higher levels of general cognitive ability are more likely to achieve insight, our results suggest that three specific types of cognitive ability contribute differentially to insight problem solving.

Convergent thinking was further broken down into working memory and verbal intelligence, the latter of which might be particularly relevant to solving linguistically presented insight problems. These two constructs also predicted insight independently of each other and of divergent thinking and ability to break frame. Finally, divergent thinking and ability to break frame were uniquely associated with insight problem solving but not noninsight problem solving, thus demonstrating discriminant validity.

Taken together, our results indicate that the ability to solve insight problems is like the ability to solve well-defined or noninsight problems (i.e., to think convergently) plus the ability to break frame and to think divergently. This is consistent with the idea that all problems may require logical operation within an appropriate problem formulation, but that ill-defined problems are distinguished from well-defined problems by the need to restructure one's formulation before solution is possible. Restructuring requires additional abilities, which cannot be wholly reliant on logic due to the impossibility of specifying relevance objectively in the nearly infinite detail of our environments (Brooks, 1991; Medin & Aguilar, 1999; Peterson & Flanders, 2002). The ability to break frame may be necessary to avoid perseveration with an incorrect problem formulation, while divergent thinking may be necessary to generate elements of a novel formulation. Convergent thinking allows effective application of logical operators, when a problem is well-defined, but it may also contribute to identification of flaws in existing problem formulations or to validation of novel formulations.

Within each of the three types of ability, it may be possible to examine more specifically differentiated cognitive abilities, much as the present study did by breaking down intelligence into working memory (a component of fluid intelligence) and verbal intelligence. Such finer differentiations may be of particular interest in the domain of divergent thinking. The present study found that, of three different indices of divergent thinking (fluency, originality, and flexibility), only flexibility was independently predictive of insight. Fluency was significantly correlated with insight, but only because of variance it shared with flexibility. This suggests that flexibility, the ability to switch repeatedly between categories or perspectives, may be particularly important in divergent thinking (cf. Runco & Chand, 1995). Indeed, generating many similar responses in the same category, which would yield a high fluency score, seems considerably less divergent and creative—and less likely to lead to restructuring and insight—than does generating responses across many categories. Future research on the association of divergent thinking with insight should compare linguistic processes, like those measured here, with visual processes, such as the ability to identify blurry or ambiguous pictures.

The identification of flexibility as the measure of divergent thinking most predictive of insight raises the question of whether flexibility and ability to break frame really represent distinct types of cognitive ability. At first, the two constructs may seem very similar, and flexibility has been suggested to aid in avoiding functional fixedness (Runco & Okuda, 1991). However, changing categories of response in the divergent thinking tasks has an important difference from identifying an anomalous playing card in the measure of breaking frame. Namely, in the divergent thinking tasks, changing categories is likely to be consistent with the manner in which the task is framed by participants. Participants are instructed to generate as many solutions as possible, and giving responses in many categories fits within this frame. Even if a participant has trouble thinking of many categories, he or she is unlikely to assume that switching categories would be inappropriate. In the anomalous card task, by contrast, the instruction is simply to describe what is seen, which does not obviously imply that more than one category of description is necessary. Participants typically assume that the task is limited to identifying normal playing cards. Thus, in order to recognize that a different category of description is appropriate for the anomalous card, participants must break out of the frame they have imposed, in a manner that is not exactly analogous to exhibiting flexibility in divergent thinking. The anomalous card task is like a simplified version of the impasse reached in insight problems, wherein a faulty assumption about how to interpret the problem constitutes a frame that must be abandoned before solution can be achieved. Only once the frame is broken is the problem-solver likely to begin the flexible divergent thinking necessary to generate a new, more appropriate frame.

The fact that neither flexibility nor the other divergent thinking scores were significantly correlated with breaking frame supports our hypothesis that breaking frame represents a separate type of cognitive ability from divergent thinking. It does not support Runco and Okuda's (1991) hypothesis that flexibility in divergent thinking might aid in avoiding functional fixedness. Breaking frame was described above as the ability that allows a transition from convergent to divergent thinking, and it seems plausible that this transition might entail a distinct cognitive process. This description also suggests that breaking frame may not be as broad a category as convergent or divergent thinking, both of which clearly encompass various separable abilities. Obviously, additional research will be necessary to test these hypotheses about breaking frame more thoroughly.

CONCLUSION

Hopefully, the model presented here may provide a useful upper level for a taxonomy of cognitive abilities, one that may guide future research on insight and the solving of ill-defined problems. At face value, the puzzles and riddles that constitute insight problems may seem to lack ecological validity. (After all, how important to human existence is being clever at riddles?) However, because insight problems are ill-defined and require restructuring, they have potential for relevance to real-life problem solving in a way that is lacking in the well-defined problems more commonly used in psychology and neuroscience. Because many problems in life, like insight problems, are ill-defined and require restructuring before they can be solved, studying insight problems may provide a window onto the fundamental questions of how human beings generate novel problem formulations and what underlies sagacity and creativity. The contrived simplicity of these insight problems is precisely what allows them to be formally specified as pure insight problems, requiring nothing more than restructuring for their solution.

Some evidence exists that insight problem solving predicts the quality of creative production in the laboratory, in tasks such as drawing and writing stories (Lubart & Sternberg, 1995), and insight appears to be an important element of creative cognitive processes in ordinary individuals (e.g., Duncker, 1945; Lubart & Sternberg, 1995; Wertheimer, 1945, 1959). Future research should investigate real-world correlates of insight problem solving and the role of insight in everyday life, but it must be remembered that outside the laboratory (or the pages of joke or puzzle books) it is rare to find a problem that requires nothing more than restructuring to achieve solution. In real life, insight may suddenly reveal a path to solution, but following that path may then be difficult or time consuming. Formal insight problems, therefore, seem likely to remain an important tool in cognitive research, and understanding the cognitive abilities and underlying brain processes that contribute to their solution is an important step toward understanding the processes involved in insight more generally. Additional research will be necessary to determine whether nonverbal types of insight problems, such as spatial or object-manipulation problems, are similarly related to cognitive abilities. Our model predicts that all of the constructs associated with verbal insight problems, with the possible exception of verbal intelligence, should contribute to performance on any insight problem.

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