Insight

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Abstract

Insight, also known as the *Aha* phenomenon, is the sudden awareness of the solution to a problem. In contrast, analysis is problem solving by consciously and deliberately manipulating the elements of a problem. The Gestalt psychologists began studying insight about a century ago. On the basis of their research with complex "insight problems," they characterized insight as a reinterpretation or restructuring of one's representation of a stimulus or situation after a period of unconscious processing. The emergence of cognitive psychology later during the twentieth century led to another period of advancement in insight research during the 1980s and 1990s. This work further characterized the unconscious nature of the processing leading up to an insight. More recently, the development of techniques for measuring and manipulating brain function has sparked a new renaissance in insight research. Cognitive neuroscience research has highlighted the key role of the right hemisphere and has discovered a number of neural precursors to insight, including its origins in patterns of resting-state brain activity and in neural preparatory activity immediately before a problem is presented. The latest trend is work aimed at developing techniques to enhance insight, including recent research showing that direct stimulation of the right hemisphere can facilitate the solving of insight problems. Cognitive neuroscience approaches should continue to fuel rapid advances and may lead to the development of practical technologies for insight enhancement.

When a person solves a problem, he or she takes a situation's initial state and transforms it into a goal state with whatever tools or "operators" are available. There are two general strategies for accomplishing this transformation. *Analytic* thought involves deliberately, methodically, and consciously applying these operators to effect the transformation. *Insight* is the sudden awareness of the solution after a period of unconscious processing (i.e., the "Aha" phenomenon).

HISTORICAL PERSPECTIVES

Insight has been a topic of interest since antiquity, but became a topic of scientific study only in the early twentieth century. Behaviorists such as Edward

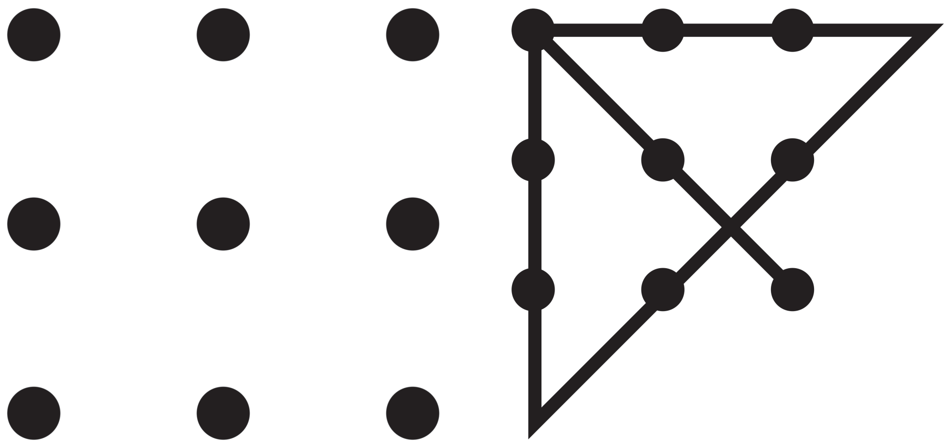
Emerging Trends in the Social and Behavioral Sciences. Edited by Robert Scott and Stephen Kosslyn.
 ISBN 978-1-118-90077-2.

Thorndike viewed learning and problem solving as a trial-and-error process by which response tendencies are gradually strengthened by rewards or weakened by punishments. In contrast, the Gestalt psychologists recognized that the behaviorist view is insufficient, as shown by studies that demonstrated discrete, all-or-none transformations in visual perception. Furthermore, Wolfgang Kőhler's studies of problem solving in apes demonstrated what appeared to be sudden insights in problem solving. His most famous study involved placing a bunch of bananas behind a fence out of the reach of a chimpanzee. Two bamboo sticks were available to the chimp, but neither was long enough to reach the bananas and pull them within reach. After a period of frustration and inaction, the chimp spontaneously arrived at the solution, namely, jamming one stick into the other—bamboo shafts are hollow—to make a longer rod that could be used to reach the bananas. Importantly, the chimpanzee had not been rewarded for intermediate steps that would have brought him incrementally closer to achieving this solution, such as holding both sticks at the same time or knocking them together. The use and construction of the tool apparently came to the chimpanzee suddenly and all at once—an insight.

Gestalt psychologists went on to demonstrate similar examples of insightful problem solving in humans. Their methodology was based around a corpus of "insight problems" that typically elicit an "Aha!" experience when they are solved. This work helped characterize insight but did not lead to great progress in understanding its underlying mechanisms. One of the main limitations with the Gestalt psychologists' research on insight was that it relied on an informal consensus regarding which problems were to be considered insight problems and which would be considered analytic problems. Thus, they did not isolate objective behavioral or experimental correlates of insight.

RESTRUCTURING AS INSIGHT SOLVING

Many classic insight problems are difficult to solve because they encourage the assumption of erroneous constraints on the solution. For instance, the very difficult nine-dot problem consists of a 3×3 matrix of dots (Figure 1a). Solvers are instructed to draw four straight lines that pass through all nine dots without lifting the pen or retracing any lines. The solution to this problem is simple, but in many laboratory studies fewer than 5% of subjects successfully solve it within the allotted time. Subjects fail to solve the problem because they assume that the solution must stay inside the square figure implied by the dots and that pivots can only be made on dots—neither stipulation being part of the explicit instructions. When one discards these constraints by restructuring one's representation of the problem so that it



(a) (b)

Figure 1 The nine-dot problem. (a) Subjects' task is to draw four straight lines connecting all 9 dots without lifting the pen from the paper and without retracing any lines. (b) A solution to the nine-dot problem. *Source*: Adapted from http://en.wikipedia.org/wiki/Thinking_outside_the_box

includes the blank background on which the nine-dot figure is presented, the solution becomes fairly obvious (Figure 1b).

INSIGHT AND FUNCTIONAL FIXATIONS

The Gestalt psychologists' main work was on visual perception. They noted that any visual object or scene is ambiguous in the sense that it can be interpreted in more than one way. One example of this is the necker cube (Figure 2a), which can be interpreted in either of two orientations (Figure 2b). When the viewer focuses attention on the lower square, this square seems to be the front face of the cube; when the viewer focuses on the upper square, that appears to be the front face. Moreover, the shift between these two perceptual representations is sudden and discrete, as in an insight.

The Gestalt psychologists generalized from such perceptual phenomena to problem solving. They viewed the main difficultly in solving a problem to be that the would-be solver started with the wrong initial representation of the problem. After restructuring, the new representation would immediately suggest a solution that would be experienced as a sudden insight.

One type of misrepresentation, called *functional fixation*, is the tendency to use objects only for their traditional functions. For example, in the classic candle problem, participants are directed to support a candle on a wall, given only a box of tacks and a match. The fact that the box is holding the tacks tends to discourage solvers from seeing it as a critical part of the solution: a

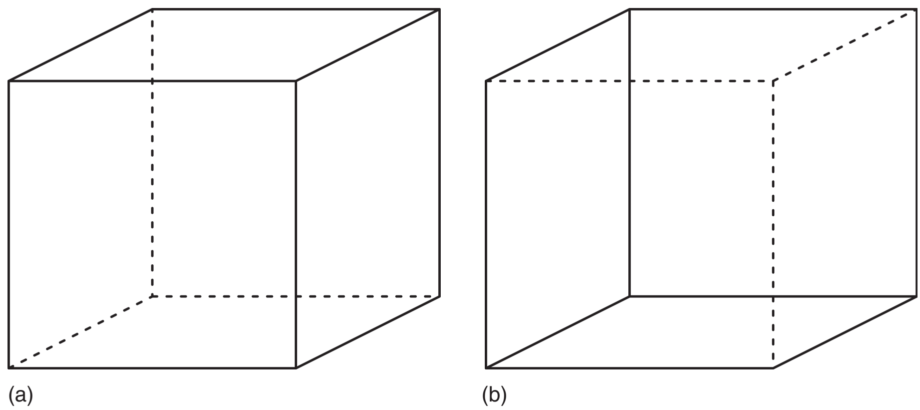


Figure 2 A Necker cube. (a) The Necker cube is an ambiguous figure that can be viewed as existing in different orientations. (b) Switching between perceived orientations is instantaneous. *Source*: Adapted from http://en.wikipedia.org/wiki/Necker_cube

shelf for the candle, to be tacked to the wall. Solution rates improve, however, when the box is presented to solvers independently of the tacks. Thus, participants tend to see the box only as a container when it is initially presented as a container. Functional fixedness is reduced when the box is not presented in its typical guise. This facilitates the solver's restructuring of their idea of the box.

THE MODERN STUDY OF INSIGHT

The emergence of modern cognitive psychology brought greater methodological and theoretical sophistication to the study of insight. For example, Metcalfe and Wiebe were among the first to identify an objective difference between insight and analytic problem solving. Their participants worked on a series of insight and analytical problems while periodically rating how close they felt to solving each problem ("warmth"). While working on analytic problems, participants indicated that they felt gradually increasing warmth before solving each problem. In contrast, while working on insight problems, participants reported low warmth until just before solving the problem. Furthermore, for those few insight problems during which participants reported gradually increasing warmth, their reported solutions were often incorrect.

Metcalfe and Wiebe's study was groundbreaking in showing a clear behavioral distinction between insight and analytic solving. However, their study did not actually show that insight solutions were derived in a discrete all-or-none manner, which is one of the defining features of insight. Following up on their work, Smith and Kounios used a new experimental procedure to force participants to make their best guess about a solution immediately before they normally would have solved the problem. Mathematical analyses enabled them to determine whether problem solving involves the gradual accumulation of solution information over time or whether solution information becomes available in a single all-or-none burst, as in insight. They used insight-like anagram problems and discovered that participants had accrued no measurable solution information before achieving the solution, showing that solution information became available to subjects in an all-or-none manner. This study confirmed the sudden, discrete nature of insight, and differentiated it from prior findings of gradual information accrual in noninsight tasks.

IMPASSE AND INCUBATION

When solvers reach a state at which they have failed to solve a problem and cannot generate new ideas or strategies, they are said to be at *impasse*. Verbal protocols in which the solver explains his or her thinking while working on a problem have identified features of impasse before solving classic insight problems. Results obtained with the verbal protocol technique have been corroborated by eye tracking studies. Before an insight solution, the duration of gaze fixation (how long the solver looks at a single part of the problem) increases. This increasing fixation means that the solver is running out of ideas to try to solve the problem, signaling impasse. However, gaze fixation tends to increase most on features of the problem that are relevant to the solution, indicating that solvers may unconsciously be collecting the information necessary for restructuring.

Why is impasse frequently linked to insight solving? One theory is that impasse often leads solvers to take a break from the problem, which allows *incubation*. Incubation breaks have been shown to increase the solution rate for classic insight problems. This can happen because time away from a problem can allow selective forgetting of incorrect strategies and assumptions, making retrieval of the correct solution more likely. Incubation by selective forgetting is supported by evidence that for incubation to impart beneficial effects, problems must be completely removed from view. Furthermore, incubation is helpful only when the original problem encourages spurious assumptions and is most successful when the solver becomes engaged in another task.

Another potential mechanism for incubation during a break is that solvers might continue to unconsciously work on the problem; however, incubation of essentially any length appears equally effective in boosting solution, which would not be expected if complex unconscious processing were the cause. Nevertheless, some form of unconscious processing may facilitate insight in some situations.

NEW METHODOLOGIES FOR STUDYING INSIGHT

The body of research on the classic nine-dot, candle, and related problems has a distinct limitation: Such "insight problems" were assumed to require insight for their solution, but lacked any empirical support for this assumption. Furthermore, work comparing the solving of such "insight" and "analytic" problems makes a related assumption, namely, that these two classes of problems differ only in the processing strategy that subjects use to solve them. While the former assumption may eventually be shown to be generally valid for classic insight problems, the latter is clearly not. Insight and analytic problems typically differ from each other in a number of ways, such as their complexity, familiarity, visual versus verbal content, and so forth. Therefore, observed differences in how people solve these problems cannot be entirely attributed to the use of an insight or an analytic strategy and may, in fact, be due to these ancillary factors.

To circumvent these limitations, Edward Bowden and colleagues developed a new methodology for studying insight. They adapted one type of problem originally developed for a test of creativity called the *Remote Associates Test*. Each of these *compound remote associates* (CRA) problems consists of three words (e.g., *pine*, *sauce*, *crab*). The solver must generate a fourth word that can be combined with each of the problem words to form a compound or familiar phrase (*apple*: *pineapple*, *applesauce*, *crabapple*).

Solving a CRA problem requires a solver to access weak, remote associations of the problem words. For example, the word *pine* strongly evokes the association *tree*, *sauce* evokes *tomato*, and *crab*, *seafood*. To find the solution word, the solver must retrieve the word *apple*, which is weakly associated with each of the problem words. This is thought to involve a type of restructuring similar to what solvers must accomplish while tackling a classic insight problem.

An interesting feature of CRAs is that they are neither insight nor analytic problems. After participants solve a CRA, they are asked to report whether they solved it in a deliberate, methodical (i.e., analytical) manner, or whether they had solved it with insight (i.e., an "Aha"), a distinction with which participants are familiar. Virtually all participants report at least a few insight solutions and a few analytic solutions. On average, about half of the solutions are of each type, although participants exhibit substantial variation about this mean.

This approach yields important benefits for insight research. Most importantly, insight and analytic solutions can be directly compared because the problems that evoked these two types of solutions do not differ in complexity, length, or any of the other factors that ordinarily distinguish classic insight problems from analytic ones. Second, because these problems are short and yield solutions within a few seconds, participants can solve many of them within a single session. This opens up the possibility of using these problems for neuroimaging studies of insight, because all neuroimaging techniques require multiple trials to yield the necessary signal-to-noise ratio.

THE HEMISPHERIC BASIS OF INSIGHT

Research has associated creative cognition with the brain's right cerebral hemisphere. In particular, the solution of CRA problems with insight is supported by visual hemifield studies. In these studies, a stimulus (such as a word) is directly presented to either the right or left hemisphere by presenting a stimulus to the left or right of a fixation point, respectively. In several experiments by Beeman and Bowden (2000) CRAs were presented with a deadline short enough that participants often failed to solve them. Immediately upon reaching the deadline, either the solution word or an irrelevant word was presented to the left visual field (which projects to the right hemisphere) or the right visual field (which projects to the left hemisphere). Participants were instructed to vocalize this probe word as quickly as possible. They pronounced solution words more quickly than irrelevant words. They also pronounced solution words more quickly when they were presented to the right hemisphere. Furthermore, solution words that were presented to the right hemisphere which also elicited an "Aha" feeling of recognition were pronounced more quickly still. Such results support the notion that insights are preceded by unconscious processing in which the solution word is weakly represented in the right hemisphere.

On the basis of visual hemifield findings and a variety of other types of research, Beeman proposed that the brain's hemispheres process semantic information differently. The left hemisphere engages in *fine semantic coding* in which each word strongly activates a small number of closely related associates, while the right hemisphere engages in *coarse semantic coding* in which a word weakly activates a relatively large number of remote associates. Insight and related forms of creative cognition primarily rely on right hemisphere coarse semantic coding that allows a person to access the nondominant meanings necessary for problem restructuring.

THE NEUROIMAGING OF INSIGHT

The first neuroimaging study to isolate insight was done by Beeman, Kounios, and colleagues. This study used functional magnetic resonance imaging (fMRI) and electroencephalography (EEG) to record participants' neural activity while they solved CRA problems. fMRI provides excellent spatial resolution but only modest temporal resolution, so it is the tool of choice for localizing brain areas that are active during a cognitive task, although it gives less precise information about the timing of this activity. In contrast, EEG affords excellent temporal resolution, but only modest spatial resolution, so it is ideally suited to delineating the timing of neural events. Together, fMRI and EEG provide powerful localization of neural activity in both space and time.

This work found that the moment of solving a CRA problem by insight (but not analytic thought) was accompanied by a burst of high-frequency ("gamma-band") EEG activity measured over the right temporal lobe. The timing of this activity coincided with participants' awareness of the solution. fMRI localized this activity to a brain structure called the *right anterior superior temporal gyrus* (aSTG). Prior research supports the involvement of the right aSTG region in integration of remotely associated pieces of semantic information, as occurs in jokes, metaphors, and other types of figurative language processing.

This study revealed an additional phenomenon associated with insight solutions: Immediately before the burst of high-frequency EEG activity coincident with the sudden awareness of the solution, there was a burst of lower frequency "alpha-band" activity measured over the right posterior cortex. EEG alpha waves are generally associated with inhibition of neural activity and, when measured over the visual cortex, are understood to reflect inhibition of visual inputs to the brain. The researchers' interpretation of this finding was that the brain reduces sensory inputs briefly in order to increase the signal-to-noise ratio of the weakly activated solution represented in the right temporal cortex. This enables retrieval of the solution into awareness, which is accomplished as a sudden insight.

The discovery of a neural correlate of insight and its immediate precursor suggested a research strategy of finding additional precursors. This is accomplished by tracing neural activity back in time starting at the moment of insight. This is important for two reasons. First, the discovery that insight and analytic solving involve different cognitive strategies and patterns of neural activity raises the question of what factors determine which of these strategies are applied toward a given problem. Second, if there is a sequence of neural precursors to insight and analytic solving, this raises the possibility that each of these precursors can potentially be influenced to change the cognitive strategy that a person uses to solve a problem.

THE PREPARED MIND

Louis Pasteur once said, "Chance favors only the prepared mind." To look for a neural basis for Pasteur's claim, Kounios and Beeman examined one type of neural precursor of insight—brain activity immediately before the presentation of each CRA problem. They hypothesized that a person prepares for or anticipates solving an upcoming problem by adopting a pattern of neural activity that will promote either an insightful or analytic solution. They found that preparation for solving an upcoming problem with insight involves (relative to preparation for analytic solving) greater activity in the anterior cingulate and in the right and left temporal lobes. By contrast, preparation for analytic solving involves increased activity in the visual cortex. The general interpretation of these results was that preparation for analytic solving involves outward focus of attention on the screen on which the problem is about to be displayed, while preparation for insight involves inward focus of attention and priming of brain areas involved in processing words and concepts. The isolation of different brain states corresponding to insightful and analytic modes of thought further supports the idea that cognitive solving strategies can be systematically primed.

One way to prime insightful thought is by manipulating mood. A number of studies have shown that a positive mood facilitates creative thought, while a negative mood facilitates analytic thought. The effect of positive mood has been localized in the brain by fMRI studies of CRA problems. In the brief preparatory phase just preceding a CRA solution by insight, a number of brain areas are activated. An increasingly positive mood is associated with activation of a different set of areas. These two sets of brain activations have an area in common: the anterior cingulate, a region involved in cognitive control and executive processes.

Prior research has shown that the anterior cingulate is involved in the detection of cognitive conflict in the brain, that is, the detection of competing response tendencies. Ordinarily, when conflicting tendencies are activated, such as pressing a button on the right and pressing a button on the left with the same hand, the anterior cingulate suppresses the weaker tendency to let the stronger one dominate. In insightful problem solving, a weaker tendency, that is, an obscure solution possibility or a remote association, must be allowed to dominate. According to this idea, activation of the anterior cingulate permits detection of weak solution ideas that might otherwise be suppressed. Thus, positive mood sensitizes a person to remote associations and "long-shot" ideas during the preparation phase.

THE INSIGHTFUL BRAIN AT REST

If the adoption of an insight mode of processing on a problem is influenced by one's pattern of brain activity immediately before problem presentation, what determines whether one adopts an insightful or analytic pattern of activity in this preparatory period? It has been shown that *resting-state brain activity*—the pattern of neural activity that occurs when a person relaxes with no task to perform—is influential to an individual's tendency to prepare to process an expected problem either insightfully or analytically. In a study by Subramanian, participants had their resting-state activity recorded before solving anagrams. They were then divided into a high-insight group and high-analytic group based on the number of insightful versus analytic solutions they had produced. When the resting-state data is compared between these two groups, the patterns of neural activity differ in several ways. Most notably, high-insight solvers tend to have more right-hemisphere activity, as well as greater activity in the anterior cingulate.

INSIGHT ENHANCEMENT

The discovery of neural precursors to insight suggests that it should be possible to develop a practical technology for enhancing or promoting insightful thought. Although such work is in a very early phase, clear directions are emerging. A straightforward example is the manipulation of mood to facilitate insight or analysis (whichever is more appropriate to the situation at hand). Another approach has emerged from social psychology research on *mindset priming.* A mindset is a theorized set of cognitive processes that can be evoked by a situation or stimulus. Once evoked, these processes bias a person to process information in a particular way. For example, *temporal construal* priming has been used to evoke a mindset conducive to insightful thought. Thinking about an event that will take place in the distant future tends to promote abstract thought, while thinking about near future events promotes more concrete thinking. Research has shown that abstract thought generated through this method facilitates insight solving, while concrete thinking facilitates analysis. Other work has shown the effectiveness of *counterfactual mindset* priming, in which a person must consider a series of hypothetical statements constructed by changing one or more elements of a scenario, for example, "If I had brought my umbrella today, then I would not have gotten wet." Thinking about such counterfactual statements has been shown to prime insight.

A more dramatic approach to insight enhancement is by direct stimulation of the brain. Two recent studies by Chi and Snyder used transcranial direct current stimulation (tDCS) while participants attempted to solve insight problems. tDCS is a very weak DC current that travels through the scalp and skull and across the brain. When this mild electrical stimulation was applied over right frontal-temporal cortex (slightly anterior to the aSTG), it increased solution rates to these problems. In a particularly striking demonstration, this pattern of stimulation increased solution rates for the classic and very difficult nine-dot problem from 0% to 40%. These results are consistent with visual half-field and neuroimaging findings pointing to a key role for the right hemisphere in insight.

Although promising, research on the effects of neurostimulation on insight is still in a very early phase. Significant questions remain. For example, while the tDCS studies by Chi and Snyder showed increased solution rates for insight problems with right-hemisphere stimulation, they did not verify that their subjects actually solved the problems with insight. Of course, for practical purposes the important thing is that a problem is solved, however this occurs. Nevertheless, further development of this approach will depend on an understanding of the cognitive mechanisms involved. It is also unclear what was altered by tDCS at the level of neural circuitry and functional neuroanatomy. Chi and Snyder's neurostimulation protocol did not permit them to infer whether the obtained insight enhancement was due to right-hemisphere stimulation or left-hemisphere inhibition (because of their placement of the reference electrode). Additional studies will undoubtedly clarify these effects, especially by combining tDCS with EEG to ascertain the effects of the neurostimulation protocol on brain activity. If insight enhancement through neurostimulation is eventually proved to be practical and reliable, then there will be potential for widespread real-world applications in education, business, psychotherapy, scientific research, or any other field in which problems must be solved.

Other neurotechnologies for insight enhancement have yet to be systematically investigated. For example, to date, pharmacological approaches have received virtually no attention. Neurofeedback, also known as *EEG biofeedback*, may help to modulate the neural processes subserving insightful and analytic thought.

CONCLUSIONS

After a spurt of cognitive psychology research on insight during the 1980s, there was a period of little progress. During the past decade, cognitive neuroscience approaches have reinvigorated insight research by revealing the outlines of its functional neuroanatomy and by elucidating the involvement of hitherto unsuspected cognitive processes, such as sensory gating immediately before insight. This recent progress has stimulated promising work aimed at facilitating insight. This work will ultimately spur additional research that attempts to identify entire networks of brain regions whose cooperative efforts make insight possible.

Another problem that will undoubtedly receive great attention in the coming years is the issue of how to define the relationship between insight and the larger domain of creativity. This relationship has not yet been clearly delineated, largely because these two concepts have themselves not yet been clearly defined. However, recent progress in insight research bodes well for creativity research. As neuroscience methods help to clarify the nature of creativity, as they have begun to do for insight, the relationship between insight and creativity will become clearer.

In sum, there is reason for great optimism concerning the future of insight research and for the future of insight itself. Insight is a powerful human ability. Understanding and harnessing it has the potential to be a disruptive development in human history that will contribute to our understanding of what it is to be human.

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