Bringing together implicit learning and incubation

Daniel Zinzow

Carnegie Mellon University, 2005

The unconscious mind is very powerful, sometimes and probably more often than we think, it is better than the conscious mind at learning and solving problems. Actually, trying to learn or solve problems consciously can be detrimental as it may interrupt the methods and work of the unconscious. Research has been done and theories formed on when and how the unconscious learns and affects conscious behavior. There are two very prominent areas within the research of the unconscious – implicit learning and unconscious problem solving. These phenomena are considered to be different but is it possible that these two phenomena can actually be accounted for by one theory? Being able to combine these two phenomena would provide an enhanced understanding of unconscious work.

Implicit Learning

Implicit learning characterizes how one develops intuitive knowledge about the underlying structures of stimulus environment (Reber, 1965, 1967) As defined by Reber (1965, 1967), implicit knowledge is characterized by two features: It is an unconscious process and it yields abstract knowledge. The implicit knowledge is the result of induction of an abstract representation of the structure that the stimulus environment displays, with this knowledge being acquired without conscious strategies.

Much research has been done that strengthens these claims of Reber (1965, 1967), most of them being done through the use of artificial grammar studies and probability learning studies.

Artificial grammar studies involve an acquisition phase and a procedure phase. The type of grammar systems used are ones that are too complex to be learned after several hours in a laboratory, allowing any noticeable results of learning to be attributed to unconscious rather than conscious learning. Second, these grammars are finite-state grammars so that the results of participants are easier to discern and understand. An example of these grammar studies is one done by Reber in 1967. In this study, subjects were told to memorize strings of letters in a supposedly rote memory experiment without being told anything about the fact they were working with rule-governed stimuli. With practice, these subjects became adept at processing and memorizing strings whereas subjects who worked with stimuli that had no order showed no such improvement. Subjects were also presented the task of discerning whether letter strings conformed or violated the rules of the grammar. In this task subjects with the ordered stimuli proved to be very capable at discerning. The interpretation of these results was that the subjects with the ordered words were using the structure of the grammar, even though they could not report explicitly what the structure was. There has been much research that has reported similar results (Brooks, 1978; Dulany, Carlson, & Dewey, 1984; Howard & Ballas, 1980; Millward, 1981; Morgan & Newport, 1981).

With probability learning, subjects learn implicitly about the stochastic structure of an event sequence to which they are exposed. This method has little to do with any explicit learning of probabilities of events. The participants, in the course of making predictions, mimic the structure of the event sequence. A result of this process of mimicking is the matching of the probabilities of the events, which is referred to as "probability learning." An example of this type of study can be shown by an experiment done by Reber and Millward in 1971. This experiment found that participants could accurately anticipate the changing probabilities of events even when the anticipatory response required an integration of information across 50 preceding events. Participants ended up creating predictions of events that rose and fell coincidentally with the actual event sequences, showing that the participants had learned the underlying structure of the stimulus environment. To further show the power of the implicit mind, a similar experiment was done but this time current events were dependent upon events of a previous trial, all the way back to the seventh previous trial. Testing revealed that the participants had a clear sensitivity to these dependencies even to the point that such capabilities were beyond those of explicit recall (Millward and Reber 1971; Millward & Reber, 1968; Reber & Millward, 1965).

Not only do the participants in these experiments have an apparent implicit understanding of the underlying complex structures of stimuli but it has been shown that these participants have a relatively similar mental model compared to the actual stimuli structure. This was researched by Reber in a thesis done in 1989 where the results of 12 experiments were compared to measure how accurate implicit mental models were in comparison to the real structure (Reber, 1967; Reber and Allen, 1978; Reber, Kassin, Lewis, and Cantor, 1980). This was measured by how accurate participants were on a recognition test where they rated a grouping of letters as conforming to the grammatical structure or as violating it. The results of Reber’s (1989) research showed that what participants acquired from the training sessions can be viewed as representative of the actual underlying structure of the stimulus environment. These results occurred in both experiments where participants are not informed that the stimuli are rule governed and also experiments where participants are provided information concerning the rules for letter order in a manner that coordinates with the rules in use for the stimuli.

This capability of implicit learning has been shown to go beyond just artificial grammar and probability learning. An experiment involving a complex ruled system that simulated economic/production systems was used implicitly by subjects to achieve production standards that were given by the experimenters (Berry & Broadbent, 1984; Broadbent & Aston, 1978; Broadbent et al., 1986). Another experiment involved a complex rule as to where stimulus would appear in a four quadrant system. The reaction times of participants of where the future location of a stimulus event would appear showed that the participants had an understanding of the complex structure even though they could give no explanation explicitly (Lewicki et al., 1987; Lewicki, Hill, & Bizot, 1988).

A study done by Reber and Kotovsky in 1997 gives even further insight into the process of implicit learning by employing loads on the working memory. This study involved using a puzzle – Balls and Boxes – of which it was not possible for one to deduce the underlying rule structure for this puzzle just from the initial description and presentation of the puzzle. Not only were the participants given this puzzle to solve, but they were also given varying amounts of loads upon the working memory. Two trials were given to the participants, both with varying loads on the working memory. The results showed that impairment on problem solving was proportional to the degree of the load on the working memory, but on the second trial this load no longer had an effect. On the second trial the participants also had a noticeable improvement, which indicates that the participants had all acquired a similar level of knowledge about this puzzle. From these results it can be concluded that a load on working memory has a detrimental effect on learning but no effect after knowledge about the puzzle has been learned. The fact that these participants had found a solution was quite apparent since all participants came to a point where they no longer made errors and ended at the solution. What is quite interesting is that this path had a similar length on both the first trial and second trial and was also was relatively the same for all participants, yet no participants seemed to realize that such occurred. They were unable to give any explicit explanation as to how they got to the final solution, which is a similar result to most of the other studies previously mentioned (Reber, 1967; Reber, 1976; Reber and Allen, 1978; Reber, Kassin, Lewis, and Cantor, 1980).

It first appears that implicit learning does not give rise to conscious understanding of what one is doing while either solving a problem or discerning what fits an unconscious grammatical structure, but research by Siegler and Stern on children reveals a different result (Siegler & Stern, 1998). In their study children were given arithmetic problems that could be solved by three methods: computation strategy, negation strategy, or a shortcut strategy. Children were given many trials in which they had to solve these math problems and after each trial they gave a verbal report of how they solved the problem. Initially, all children used either the computation strategy or negation strategy which took an average of 12 seconds to solve one problem. This experiment presented some very interesting results; children would all of a sudden solve problems in 4 seconds or less yet still admit to using either the computation or negation strategy. After a couple of more trials the child would then state that they were using the shortcut strategy. These results reveal that the unconscious was solving the math problems without the children even realizing it – similar results as the other implicit learning studies previously mentioned. The difference in this study, though, is that shortly after the strategy appeared to be used by the unconscious the children would verbally say that they were using such a strategy.

Several studies done by Goldin-Meadow with co-workers give further results of working memory load and unconscious becoming conscious. These studies were also done on children, but more focused on their gesture and verbal explanations for solving solutions (Goldin-Meadow et al., 1993; Goldin-Meadow, Nusbaum, Garber, & Church, 1993; Church & Goldin-Meadow, 1986). Children who showed a lot of mismatches between gestures and verbal explanations (discordant children) had a larger repertoire of strategies than children who had very few mismatches (concordant children). The extra strategies of the discordant children were mostly shown in their gestures only with no representation in the verbal explanations. To add to that, when the children were given a second task of memorizing a word list to do while trying to solve math problems, the discordant children did not recall this word list as well as the concordant children. It appears that the discordant children were working harder on the math problem even though they still ended up giving incorrect solutions (the concordant children gave the same amount of incorrect answers too). This gives support to the results found by Reber and Kotovsky (1997) that load on the working memory affects the learning process, whereas in this case with the children the secondary task suffers as the children work hard to find a "correct" solution to the primary problem. With loaded memory it apparently becomes more difficult to handle searching the many hypotheses of how to solve a problem, causing the learning process to become much more difficult. These studies done by Goldin-Meadow and coworkers also revealed a relationship between gestures and speech (between implicit and explicit knowledge). Discordant children in the Goldin-Meadow et al. (1993) study produced some correct explanations with all of them appearing in the gestures, but the children still produced incorrect solutions on the task. In a similar study, when children produced a correct verbal response it was found that this strategy was actually produced previously in their gestures (Church & Goldin-Meadow, 1986). Reber and Lewis (1977) give some similar results that show that knowledge acquired from implicit learning procedures is always ahead of a person's ability to understand the meaning of this knowledge. In this 1977 study done by Reber and Lewis, participants solving anagram puzzles of an artificial grammar improved in their ability to verbalize the rules that they were using through practice over time, but at the same time they were also developing richer and more complex rules.

Siegler and Stern (1998) give use the concept of activation as an explanation for their results but it also appears to be applicable to all of these results by Goldin-Meadow and co-workers and Reber and co-workers. The results that Siegler and Stern (1998) found, which are that children using a shortcut strategy unconsciously before becoming conscious, gives rise to their explanation that unconscious discoveries are reflective of a lower level of activation than conscious ones. There is enough activation to surpass the threshold of execution but not the threshold of consciousness. This theory explains the results of children when they started to use the computation strategy but in mid progress switched to the shortcut strategy. The explanation for this is that during the problem solving, the activation of the shortcut strategy increases until it is strong enough to compete with the activation of the computations and it keeps rising to a level that leads to the cessation of the computation strategy. Siegler and Stern (1998) had some children solve mixed problems, in which only half could be solved with the shortcut strategy, and a block set where all could be solved by the shortcut strategy. In the mixed set, the shortcut strategy was used less often and took longer to come into consciousness, which can be explained by the fact that there was competing strategies with similar levels of activation as the shortcut. As a result, any strategy would be used until one strategy has a much higher activation level than other strategies.

From these results of Goldin-Meadow and co-workers' studies, Arthur S. Reber and co-workers' studies, Paul J. Reber and Kotovsky's study, and the study of Siegler and Stern (1998) it appears that there are at least three levels of the unconscious knowledge. One level is that there is a correct solution in the unconscious but it has not yet been integrated into task performance - in other words it hasn't passed the execution threshold. The next level is that the unconscious is integrated and used but a person is not consciously aware of the unconscious solution that is being used – it hasn't passed the conscious threshold. Finally, the unconscious solution becomes consciously known and can be used for solving problems.

Incubation – Conscious to Unconscious to Conscious

The definition of incubation is quite difficult to define considering that different researchers have different definitions for the term. The general concept that is expressed by Woodworth (1938), Wallas (1926), Hemholtz (1896), Poincare (1908), Glass & Holyoak (1986), Hadamard (1945), and Patrick (1935) is that of putting a problem aside and attending to other matters. When this incubation period is over there is a sudden insight that the problem solver gains. There are many different theories that explain what occurs during this incubation period, such as Unconscious Work, Conscious Work, Forgetting, Priming, amongst others. All these theories do not have much support since they do not have undisputable experimental evidence, which is hard to acquire considering one is dealing with the unconsciousness. To keep away from selecting one theory over another, incubation will be referred to as an increased likelihood of successfully solving a difficult problem by placing a period of "unconscious" work between an initial period of intense conscious work and a subsequent period of conscious work that results in a solution.

With this definition in mind, the next step is to look at some ideas of what happens during that unconscious period of time that allows the problem solver to have a sudden insight. The process of incubation is similar to that of trying to answer questions about relatively unfamiliar facts; in both situations there is an unsuccessful attempt to have a solution/answer for a difficult problem/question, which is then followed by a subsequent period where mental elements come together to provide a solution. Yaniv and Meyer (1987) proposed that this solution that appears may be created from the retrieving and integrating of diverse pieces of information that are connected through remote associations within the long-term memory (Blucksber & Weisberg, 1966; Judson, Cofer, & Gelfand, 1956; Penney & Winsor, 1982; Weisberg & Alba, 1981). One possible way in which this may occur, that Yaniv and Meyer tested with their experiment in 1987, is that when one fails a problem, memory traces are activated and through experience with new environmental stimulus inputs, these traces will be connected with new stimuli and other associations to produce a good solution (Gick & Holyoak, 1980; Judson et al., 1956; Penney & Winsor, 1982; Read & Bruce, 1982). This study also applied the concept of feeling-of-knowing, which has been shown by Metcalfe (1987) to be a good sign to whether a solution is an insight, as in it just suddenly appears, or whether a solution comes more gradually. Yaniv and Meyer (1987) used a procedure wherein they presented participants with a rare-word definition task, feeling-of-knowing judgments, a lexical-decision task, and finally an old-new recognition task. In the rare-word task, participants were presented with definitions for rare words and asked for the word. For the definitions that the participants had no answer for (no-recall words), they gave a judgment on their feeling-of-knowing for that unknown word. The lexical-decision task and old-new recognition task were used to test for any priming effects upon the semantic and episodic memory. Results of the experiment show that the no-recall words have a shorter response time than for control words in the lexical-decision task and the old-new recognition task. The participants also made decisions about these no-recall targets more quickly when they expressed strong feelings of knowing than when they expressed weak feelings of knowing. It appears from these results that temporarily inaccessible memory traces are partially primed by an initial stimulus and that this priming may later influence semantic and episodic memory performance (Yaniv & Meyer, 1987). Yaniv and Meyer (1987) constructed a hypothesis, the *memory-sensitization hypothesis*, to explain these results. This theory states that

> "The initial unsuccessful attempt to solve a problem may partially activate stored, but currently inaccessible, memory traces critical to the problems' solution. Then, during a subsequent intervening period of other endeavors, the activation may sensitize a person to chance encounters with related external stimuli that raise the critical traces above threshold and trigger their integration with other available information. (p. 200)"

Other studies have shown similar results of activation as having a facilitation effect that helps the person find a correct solution (Fischler, 1981; Fowler, Wolford, Slade, & Tassinary, 1981; Marcel, 1983). The Zeigarnik effect (Zeigarnick, 1927) provides some more insight into this topic of activation by having demonstrated that interrupted tasks are significantly more likely to be recalled at a later time compared to uninterrupted tasks. This provides support for the idea of there being activation of unsolved work, which then would prepare the mind for any new stimuli that may be helpful in solution solving.

In the dissertation by Kaplan in 1989, he constructs a unified theory for incubation in which there is an interaction between mechanism for incubation and the difficulty that the subject experiences. Two types of difficulty can occur, that with generating new ideas for the problem and evaluating the approaches so far generated. The most common type of difficulty that has occurred in past experiments on incubation have been of generating new ideas or approaches to the problem. The two mechanisms that have an effect with this type of difficulty are diminution of interference and priming. The priming affect is the same as the memory-sensitization theory of Yaniv and Meyer (1987). The concept of diminution of interference is as follows. Retrieval of incorrect strategies from memory during initial problem solving blocks retrieval of the correct strategy to solving the problem. Overcoming this problem requires forgetting these incorrect strategies so that the correct strategies can be more accessible. This forgetting occurs during time taken away from the problem, during the time known as incubation.

A compatible idea to the diminution of interference is the three-process theory of insight (Davidson, 1995; Davidson & Sternberg, 1986). These three processes involve the mental processes of selective encoding, selective combination, and selective comparison. Davidson (1995) states that these processes are used to restructure one's mental representation which is crucial for insightful problem solving. Selective encoding involves restructuring one's mental representation to view information that was originally seen as irrelevant as relevant and information that was originally seen as relevant may be viewed as irrelevant. Selective combination is when a previously unused, and often unobvious, framework for the relevant elements is discovered. Finally, selective comparison occurs when one suddenly discovers a connection between new information and prior knowledge that was before unobvious. Incorporating the theory of diminution of interference with this three-process theory, results in a conclusion that taking time away so that incorrect strategies become less accessible allows mental representations that were not considered before to form and quite possibly construct a solution.

Implicit Learning and Incubation

Both implicit learning and incubation involve unconscious work, but at first look appear to be different phenomena. The underlying difference being that incubation involves the process of doing conscious work, then unconscious work, and finally conscious work with an insight, whereas implicit learning does not have this conscious part. To further that point, the definition given by Reber

(1965, 1967) is that implicit learning is characterized by two features, one of those being that it is an unconscious process. What is of interest is whether these two different phenomena can be incorporated by one overall theory. To investigate this possibility it is important to look at, compare, and contrast the processes of both implicit learning and incubation.

To begin, there is the first conscious part of incubation which does not occur in implicit learning. This difference can be easily accounted for when considering some studies that have been conducted involving the addition of explicit knowledge to the implicit learning tasks. In the study done by Reber in 1976, one group of participants were encouraged to search for a structure in the stimuli in an artificial grammar learning experiment while another group was given neutral instructions. The whole experiment was otherwise the same for both groups. The results showed that the explicitly instructed participants did worse in all aspects of the experiment than those of the neutral instruction group. This explicitly instructed group of participants showed evidence of having induced rules that were not representative of the actual grammar structure shown, their responses were worse at determining whether strings of letters were grammatical or not, and lastly, they took longer to memorize the exemplars. Similar research has revealed a reduction in performance when participants are made conscious of goals for the experiment (Brooks, 1978; Reber, Kassin, Lewis, & Cantor, 1980; Howard & Ballas, 1980). There have also been studies that show explicit instructions to be beneficial also (Howard & Ballas, 1980; Reber et al., 1980). In the cases that revealed positive effects of explicit instructions the manner in which the stimuli were presented was such that the underlying factors of the grammar were rendered salient. This proceeded to orient the participants toward the relevant invariances. In some cases (Reber, 1966; Reber & Millward, 1968) when subjects were given explicit instructions that guided them, the participants claimed that the instructions lacked meaning that they felt could be used. It took real experience for these participants to acquire a knowledge base representative of the underlying structure of the stimuli. Even though the explicit instructions guided the participants, it did not give them a useable, comprehensible structure. For the cases, though, in which the explicit instructions were detrimental, these instructions encouraged the participants to deal with the stimuli in a way that was discoordinate with the underlying structure. This gives rise to the explanation that competing strategies result in increased difficulty in solving a problem. These cases are ones which are considered within the realm of implicit learning, yet they show similarities to incubation in that the participants are initially conscious of the situation at hand and then have a difficult time solving the problem due to competing theories. Just as the detrimental effects of explicit instructions that give discoordinated structures is similar to difficulties in solving problems in incubation experiments, it seems quite logical that when explicit instructions are beneficial in implicit learning experiments the same would be true for incubation experiments. In other words, if a participant were to be given explicit instructions that gave direction and a salient understanding of the underlying structure of the problem, he would be much more successful.

Actually, Alibali in 1999 gave results that showed just that. Children were separated into groups that varied upon the type of instructions given and were given arithmetic problems to solve. The type of instructions given were feedback, principle, analogy, procedural, and no instruction. The group that did the best was the one in which the children were given procedural instructions of how to solve the arithmetic problems. This group was much more accurate than the other groups in solving the arithmetic problems. In the control group where the children received no instruction, they did not generate any correct solutions. These results suggest that when procedural information of the underlying structure of a problem is given in incubation problems, participants do much better. These results reveal that consciousness of the problem at hand has the same effect upon implicit learning as it does on incubation problems. This similarity being that conscious realization of the goal of the problem at hand is often detrimental; it is better to give no instructions or if instructions are given they should be given in such a way that makes the structure of the problem clear to the participants.

The second area of difference between incubation problems and implicit learning is the appearance of strategies from the unconscious to the conscious. In the cases of implicit learning where the strategy does become conscious, the strategy first appears in usage by the participant before the participant becomes consciously aware of it (Siegler & Stern, 1998). The explanation for the gradual process of unconsciousness to consciousness of solutions in implicit learning, as given earlier, is that the solution must first be activated enough to cross the threshold of execution, and then be activated even more to cross the threshold of consciousness. With incubation, on the other hand, the solution for the problem at hand immediately comes into consciousness (Metcalfe, 1987). This makes it initially seem that the unconscious process that occurs in incubation problems is different than the one for implicit learning. If one takes a deeper look at the problems and processes used for incubation, the answer becomes quite clear. With incubation problems the participant is consciously presented with a hard problem and asked for a solution. There is no process that the participant is taken through, there is just a problem before their eyes. If the solution to the problem is within the realm of execution it will not be expressed or observed since there is no task and no trials a problem solver must go through as such is the case for implicit learning experiments. Therefore the solution must gain enough activation to achieve consciousness, where the problem solver gets an insight and knows the solution to the answer, before the solution can be observed or acknowledged. As can be seen, both implicit learning and incubation problems involve a process of activation to bring an unconscious solution to consciousness. This process begins with the solution in the unconscious realm. With enough activation due to such mechanisms as priming or interference diminution (Kaplan, 1989; Yaniv & Meyer, 1987), the solution enters the execution realm where the solution is used by a person yet the person is not conscious of this solution. Finally, with enough activation, the solution enters the conscious realm. This concept of activation is able to bring these two separate areas of unconscious work together and helps to give explanation to how these two phenomena work.

The differences between implicit learning and incubation can now be seen as a result of definition not of underlying structure as the theory of activation explained in this paper can be used to provide explanation for the processes and results of both types of phenomenon. Forming an overall theory that encompasses these two theories helps provide a more cohesive understanding of unconscious learning and problem solving. This is just one step in understanding the structure and working of unconscious work and, even more abstract, the unconscious mind. The potential of applying knowledge of the structure of unconscious learning and problem solving, even a primitive, incomplete structure, is great, especially in areas of education and expertise. Another important area that this knowledge has great potential is to give further understanding into consciousness. As we learn more of what the unconscious is capable, it creates more questions as to what is the need and/or purpose of consciousness.

References

Alibali, M. W. How children change their minds: strategy change can be gradual or abrupt *Developmental Psychology, 1999 35(1),* 127-145.

Alibali, M. W. (1999). How children change their minds: Strategy change can be gradual or abrupt. *Developmental Psychology, 35(1),* 127-145.

Baddeley, A. D. (1963). A Zeigarnik-like effect in the recall of anagram solutions. *Quarterly Journal of Experimental Psychology, 15,* 63-64.

Berry, D. C., & Broadbent, D. E. (1984). On the relationship between task performance and associated verbalizable knowledge. *Quarterly Journal of Experimental Psychology, 36,* 209-231.

Broadbent, D. E., & Aston, B. (1978). Human control of a simulated economic system. *Ergonomics, 21,* 1035-1043.

Broadbent, D. E., FitzGerald, P., & Broadbent, M. H. P. (1986). Implicit and explicit knowledge in the control of complex systems. *British Journal of Psychology, 77,* 33-50.

Brooks, L. R. (1978). Nonanalytic concept formation and memory for instances. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and categorization* (pp. 169-211). New York: Wiley.

Brooks, L. R. (1978). Nonanalytic concept formation and memory for instances. In E. Rosche & B. B. Lloyd (Eds.), *Cognition and categorization* (pp. 169-211). New York: Wiley.

Chronicle, E. P., MacGregor, J. N., & Ormerod, T. C. What makes an insight problem? The roles of heuristics, goal conception, and solution recoding in knowledge-lean problems. *Journal of Experimental Psychology: Learning, Memory, and Cognition. 2004, 30(1)*, 14-27.

Church, R. B., & Goldin-Meadow, S. (1986). The mismatch between gesture and speech as an index of transitional knowledge. *Cognition, 23,* 43-71.

Davidson, J. E. (1995). The suddenness of insight. In R. J. Sternberg, & J. E. Davison (Eds.), *The nature of insight* (pp. 125-155). New York: Cambridge University Press.

Davidson, J. E. (2003). Insights about insightful problem solving. In Davidson, J. E., Sternberg, R. J. (Eds.) *The psychology of problem solving* (pp. 149-175) New York,: University Press

Davidson, J. E., & Sternberg, R. J. (1984). What is insight? *Education Horizons, 64,* 177-179.

Dulany, D. E., Carlson, R. A., & Dewey, G. I. (1984). A case of syntactical learning and judgment: How conscious and how abstract? *Journal of Experimental Psychology: General, 114,* 25-32.

Fischler, I. (1981). Research on context effects in word recognition: Ten years back and forth. *Cognition, 10,* 89-95.

Fowler, C. A., Wolford, G., Slade, R., & Tassinary, L. (1981). Lexical access with and without awareness. *Journal of Experimental Psychology: General, 110*, 341-362.

Gick, M. L., & Holyoak, K. J. (1980). Analogical problem solving, *Cognitive Psychology, 12,* 306-355.

Glass, A. L., & Holyoak, K. J. (1983). *Cognition* (2nd edition). New York: Random House.

Goldin-Meadow, S. (1993). Whend does gesture become language? A study of gesture used as a primary communcation system be deaf children of hearing parents. In K. R. Gibson & T. Ingold (Eds.), *Tools, language and cognitions in human evolutions (*pp. 63-85). Cambridge, England: Cambridge University Press.

Goldin-Meadow, S., Alibali, M. W., & Church, R. B. (1993). Transitions in concept acquisition: Using the hand to read the mind. *Psychological Review, 100,* 279-297.

Hadamard, J. (1954). *The psychology of invention in the mathematical field*. Princeton, NJ: Princeton University Press.

Howard, J. H. & Ballas, J. A. (1980). Syntactic and semantic factors in the classification of nonspeech transient patterns. *Perception and Psychophysics, 28,* 431-439.

Judson, A. J., Cofer, C. N., & Gelfand, S. (1956). Reasoning as an associative process: II, "Direction" in problem solving as a function of reinforcement of relevant responses. *Psychological Reports, 2,* 501-507.

Kaplan, C. A. (1989). *Hatching a theory of incubation: Does putting a problem aside really help? If so, why?* Dissertation, Carnegie Mellon University.

Kotovsky, K. & Reber, P. J. Implicit learning in problem solving: the role of working memory capacity. *Journal of Experimental Psychology: General. 1997 126(2),* 178-203.

Lewicki, P., Czyzewska, M., & Hoffman, H. (1987). Unconscious acquisition of complex procedural knowledge. *Journal of experiment Psychology: Learning, Memory, and Cognition, 13,* 523-530.

Lewicki, P., Hill, T., & Bizot, E. (1988). Acquisition of procedural knowledge about a pattern of stimuli that cannot be articulated. *Cognitive Psychology, 20,* 24-37.

Marcel, A. J. (1983). Conscious and unconscious perception: Experiments on visual masking and word recognition. *Cognitive Psychology, 15,* 197-237.

Metcalfe, J. & Wiebe, D. Intuition in insight and noninsight problem solving. *Memory & Cognition, 1987, 15(3)*, 238-246.

Millward, R. B., & Reber, A. S. (1968). Probability learning: Contingent-event sequences with lags. *American Journal of Psychology, 85,* 81-98.

Morgan, J. L.,& Newport, E. L. (1981). The role of constituent structure in the induction of an artificial language. *Journal of Verbal Learning and Verbal Behavior, 20,* 67-85.

Patrick, C. (1935). Creative thoughts in poets. *Archives of Psychology,* 178.

Penney, C. G., & Winsor, B. (1982, November). *Incubation viewed as a retrieval phenomenon.* Paper presented at meeting of Psychonomic Society, Minneapolis, Minnesota.

Read, J. D., & Bruce, D. (1982). Longitudinal tracking of difficult memory retrievals. *Cognitive Psychology, 14,* 280-300.

Reber, A. S. (1965). *Implicit learning of artificial grammars.* Unpublished master's thesis, Brown University.

Reber, A. S. (1967). Implicit learning of artificial grammars. *Journal of Verbal Learning and Verbal Behavior, 77,* 317-327.

Reber, A. S. (1976). Implicit learning of synthetic languages: The role of instructional set. *Journal of Experimental Psychology: Human Learning and Memory, 2,* 88-94.

Reber, A. S., & Allen, R. (1978). Analogy and abstraction strategies in synthetic grammar learning: A functionalist interpretation. *Cognition, 6,* 189-221.

Reber, A. S., & Lewis, S. (1977). Toward a theory of implicit learning: The analysis of the form and structure of a body of tacit knowledge. *Cognition, 5,* 333-361.

Reber, A. S., & Millward, R. B. (1965). Probability learning and memory for event sequences. *Psychonomic Science, 3,* 431-432.

Reber, A. S., & Millward, R. B. (1971). Event tracking in probability learning. *American Journal of Psychology, 84,* 85-99.

Reber, A. S., Kassin, S. M., Lewis, S., & Canotr, G. W. (1980). On the relationship between implicit and explicit modes in the learning of a complex rule structure. *Journal of Experimental Psychology: Human Learning and Memory, 6,* 492-502

Siegler, R. S. & Stern, E. (1998). Conscious and unconscious strategy discoveries: a microgenetic analysis. *Journal of Experimental Psychology: General, 27(4)*, 377-397.

Wallas, G. (1926). *The Art of Thought*. New York: Harcourt, Brace.

Weisberg, R. W., & Alba, J. W. (1981). An examination of the alleged role of “fixation” in the solution of several “insight” problems. *Journal of Experimental Psychology: General, 110*, 169-192

Woodworth, R. S. (1938). *Experimental Psychology,* New York: Holt.

Yaniv, I., Meyer, D. E. (1987). Activation and metacognition of inaccessible stored information: Potential bases for incubation effects in problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 13(2)*, 187-205.