Selected Proceedings of the 3rd Asia-Pacific Conference
Seoul, Korea, August 1-4, 1994

Some Aspects of the Creative Mind: A Cognitive Learning Perspective

Seong-Soo Lee, Canada

Introduction

The Italian educator Maria Montessori once remarked that "Creativity is in the prepared mind". She advocated children's self-regulated learning by capitalizing on a child's desire to manipulate objects and develop insights on his or her own. I was particularly interested in the phrase "the prepared mind". To date, I have often seen many references that have alluded to the notion that every individual has creative potential. However, although this interpretation may sound ideal, I feel that it may be too unconstrained. Hence, I look upon the idea of "the prepared mind" as a conceptual arbitrator, that can force us to be more specific about this idea.

"The prepared mind" can be considered prepared pre-natally, post-natally or both. As a psychologist, I should look at the subject from the point of view that 'preparation' is both pre- and post-natal. But I decided to take a more functional viewpoint and examine the parameters of the creative mind from a post-natal learning perspective. In short, the creativity of gifted people (as stated by Albert and Runco, 1989; Sternberg & Lubart, 1993) does not flash nor emerge out of the blue, but instead evolves in individuals who possess a well-prepared knowledge-base and cognitive skills. Before I continue my analysis of the creative mind, I think it would be useful to briefly survey the kinds of implicit views people have concerning the concept of creativity.

Implicit Theories and Prediction Studies of Creativity

All people, including creative achievers, professionals, parents and teachers, have their own subjective views of 'creativity'. Such Implicit theories may act as prototypes against which to compare behavior. These theories are also involved whenever an individual makes judgements about his/her own or others' behavior. Sternberg (1980) reported on the results of two studies based on the self-reported or self-sorting verbally described characteristics of 'creativity'. Some agreement on the perceived dimensions of creativity, intelligence, and wisdom was found among professors of art, business, philosophy, and physics, as well as college students and laypeople. Intelligence and wisdom showed the most overlap in these perceived dimensions, and creativity and wisdom the least. Also, the structure of these perceived dimensions appeared to be reflected in their judgements of others.

Not surprisingly, the layperson's conception of creativity overlaps with their conception of intelligence, with much less emphasis on analytic abilities. Specialists' conception of creativity overlaps across different fields and with laypeople's. Nevertheless, professors of art, business, and philosophy had emphasized the creative individual's (1) imagination and originality, and ability to try new ideas, (2) generation and exploration of new ideas, novel business services and products, and (3) imaginative idea combinations, and creating classification and systematization of inconvenient constructs. Physics professors showed a particular emphasis on an individual's inventiveness, his ability to find order in chaos and in basic principles and explanations, and his creative problem solving. Runco(1990) also reports on how much overlap exists among artists, teachers, and parents when they were asked to nominate adjectival descriptors of creative individuals. The parents and teachers appear to use their own implicit theories of creativity when they evaluate the originality of the ideas given by their children and students. Both Sternberg (1988) and Runco(1990) suggested that people's implicit theories of creativity should be incorporated in new creativity test developments.

The upshot of these implicit theories of creativity is whether or not they can advance us to a better understanding of the specific parameters of creative processes and help us formulate a specific plan for nurturing them. As you can see in Table 1a and 1b, it seems clear that the major features of what these implicit theories capture is the characterization of the creative individual. The characterization is inevitably to the exclusion of *task environments* (domains, fields, and contexts) to be worked on and with via the cognitive processes, which should ultimately be destined to yield the creative product. Since there are so many definitions of 'creativity' as a construct, I do not wish to add another one. I

Table 1. Characteristics of Creative Persons, as Listed by Implicit Theorists

1a): 20 characteristics listed... Tardif and Sternberg (1988)

1. Copes well with novelty	4. Thinks logically
1. Prefers nonverbal communication	4. Escape perceptual set & entrenchment
1. Create internal visualization	4. Builds new structures
2. Originality	4. Finds order in a chaos
2. Articulate verbally fluent	4. Asks 'Why'
2. High intelligence	4. Questions norms & assumptions
2. Good imagination	4. Alert to novelty & gaps in knowledge
2. Flexible and skilled decision maker	4. Uses wide categories & images
2. Makes independent judgement	4. Uses existing knowledge as a base for new ideas
3. Creative in a particular domain	4. Thinks metaphorically

The original listing complied from scholar's views on creativity by Tardif and Sternberg (1988) (reordered)

1b): Top 10 Items of the Beyonder Checklist by Torrance (1992)

1. Delight in deep thinking	6. Feeling comfortable as a minority of one
1. Tolerance of mistakes	7. Being different
3. Love of one's work	8. Not being well-rounded
4. Clear purpose	9. Sense of mission
5. Enjoying one's work	10. Courage to be creative

would rather begin by first constraining my definition in the task/context and, hopefully, the ultimate product to be referred to as 'creative'.

A great scientific discovery or work of art is surely the outcome of problem solving activity, rather than of separate small incidental pieces of work. Given the task context of an ill-defined or ill-structured problem, one's creativity can be realized in discovering an original and socially-valued solution to the problem through "an inductive leap"; that is, by combining ideas from widely separate or disparate domains of knowledge. This notion of creativity is not a new one. In early 1960, during the heyday of associative/behavioral psychology, this view was espoused by Robert M. Gange, an eminent experimental and educational psychologist. However, this view was not given much attention by most mainstream researchers.

At that time, the "zeitgeist" that prevailed in the North America research community was influenced by the demands of the field (Davis and Rimm, 1994) to quicken the identification of the creative potential of gifted and talented youth. It spawned the development of creativity tests, starting with Guilford (1956, 1967) and his associates' efforts to psychometrically define "creativity" in terms of divergent thinking(production) within the framework of the three dimensional 'structure of intellect'. Its components thus defined and later developed by Torrance(1966) include: originality, fluency, flexibility, inventiveness, and elaboration.

A brief sketch of recent psychometric development and research will suffice for my interest here.

Cooper(1991) contends that these measurements only partially tap the ability of divergent thinking and production, but do not sufficiently reveal 'originality'. Further, Runco(1993) pointed out that most descriptions of divergent thinking seem to emphasize its passive and associative aspects when in fact divergent thinking is not of a passive nature. He also noted that the only moderate predictive validity of the divergent thinking test is obtained from its natural criterion performance, which goes up to a respectable validity coefficient of approximately 0.45, when used within a specific domain of interior design. Torrance(1992) reported that the TTCT's 30-year follow-up predictability of

Table 2. Six Measures of Assessing Creative Potentials Examined (Cooper, 1992)

1) Torrance (1966) - Torrance Tests of Creative Thinking (TTCT)
2) Williams (1980) - Creativity Assessment Packet (CAP)
3) Meeker (1969) - Structure of Intellect Learning Abilities Test (SILAT)
4) Torrance, et al. (1981) - Thinking Creatively with Sounds and Words (TCSW)
5) Torrance (1981) - Thinking Creatively in Action and Movement (TCAM)
6) Khatena & Torrance (1976) - Khatena-Torrance Creative Perception Inventory (KTCPI)

creative achievement had a linear correlation of 0.25 ($p<0.02$).

One may wonder why the predictability of subsequent creative achievement from the premier test of creative divergent thinking and production (declines from) 0.46 (7 years later) and 0.51 (12 years later) ($p<0.01$, Torrance, 1972). The answer to this question is neither simple nor clear. One can only venture to list the possible sources of this confusion. Torrance(1992) attributed the low prediction coefficient to various forces that dominate over creative ability, intelligence, and high school achievement. These forces include: *Love of one's work, persistence, purpose in life, love of challenge, diversity of experience, high energy level, a sense of mission, and other Beyonder (i.e. creative achiever) characteristics.* Clearly, the forces listed relate to motivational factors, rather than to cognitive abilities and basic high school academic achievement.

Without having to examine more longitudinal follow-up studies, one can say that it is a remarkable psychometric feat to demonstrate a 30-year predictive validity coefficient of 0.25 on the basis of a test such as the TTCT, which only taps a limited range of cognitive abilities of creativity.

The ideas emerging from people's implicit theories of creativity and the lack of the predictive validity of the psychometric attempt to understand creativity seem to suggest a shift in our endeavor. This is, we need to deal with the problem in a more comprehensive context. Sternberg(1993) remarks on creatively gifted individuals, who can "buy low and sell high". This metaphoric phrase seems to advocate an approach of combining six resources that function interactively: intelligence, knowledge, styles of thinking, personality, motivation, and environment. Alternatively, as you can see in Figure 1, such multiplicate aspects of the individual can be viewed as situated in certain environmental contexts, but directed toward task-oriented learning and creating activities. In the diagram, the focus is on the striving individual who is thoroughly immersed in the cognitive activities that will be carried on up to the pinnacle of creative achievement in due course and time.

The Basics of Knowledge and Skills Acquisition and Transfer

I have noted earlier that what people's implicit theories of creativity are

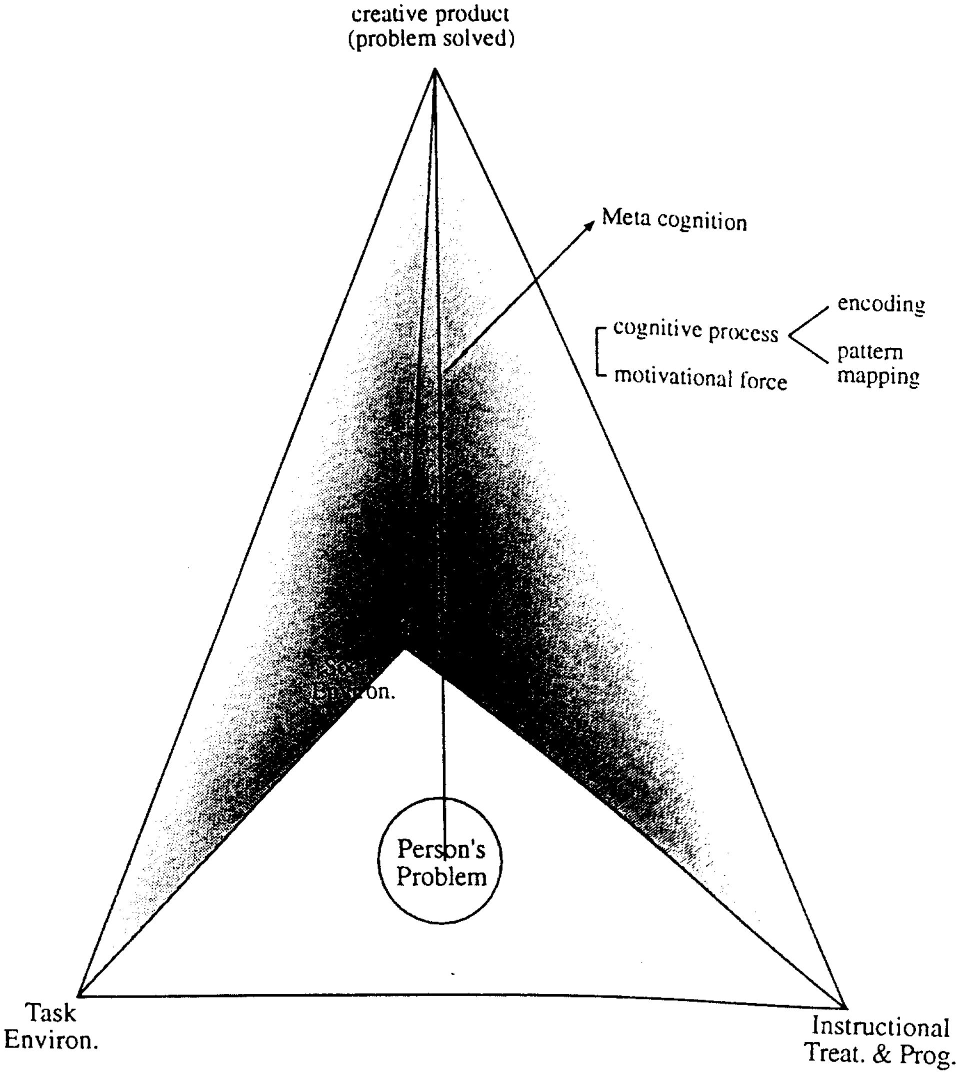

Figure 1. Person's goal, cognition, and Context.

and what some prediction studies of creative achievement can tell us is of limited value. In order to reveal authentic information about how the creative mind works, we need to take a different approach than the ones accepted in current research. The approach I have taken is a biased one, which is based on the constructs of "learning and transfer". Learning is seen as the acquisition of new knowledge and skills, and transfer is seen as the generalization or application of prior learning (acquisition) to new learning and problem solving. These two constructs are intertwined. In view of the cumulative nature of human learning, one can say that all learning are transfer-based. The primary thesis of my view on creative processes in learning and transfer is that the creative solutions (thereby a new discovery) to ill-defined or ill-structured problems can be found by the spontaneous transfer of prior learning in the form of insightful applications.

An often-cited example of a creative problem solving comes from the invention of the kinetic theory of gases. Prior to the invention of the theory, two empirical gas laws stating relationships among the variables of temperature, pressure, and volume were known. These laws are described in Table 3 as your recall aid.

On the basis of the already existing knowledge base, a new scientific insight was captured through the creative restructuring/reorganizing of ideas. This insight was *the explanatory hypothesis* that gas was composed of particles (molecules) that had mass whose reactions to force could, therefore, be considered to obey the laws of motion. This restructured integration across domains was accompanied by the universal gas law that combined the three empirical laws into a single statement: $PV=nRT$.

From the above example, it is rather obvious that this breakthrough of scientific insight could not possibly have come about had there not been the knowledge base of the previous empirical discoveries and their accompanying cognitive skills. This example leads us to examine the fundamentals of how knowledge and skills develop to create the prepared mind (Phase I) and how an available knowledge-base and skills effectively transfer to the solution to novel challenging problems (Phase II). I will begin by elaborating upon Phase I and II of an individual's mental model, which are diagrammed in Figure 2.

Table 3. An Example of Models of Explanatory Hypothesis and Empirical Laws (A Case of the Kinetic Theory of Gases)

Level 2. The Theoretical Model :
The gas is composed of particles (molecules) that has mass, whose reactions to force could, therefore, be considered to obey the laws of motion.

Universal Gas Law : PV = nRT

Level 1. Empirical Laws :

Boyle's Law (1662)	Avogadro's Law (1811)	Charles' Law (1787)
(PV = constant)	(Equal Vs of different gases all contain the same number (mole) of particles)	(V/T = constant)
if no change in T or the number of particles in a container		if no change in P

N.B. P stands for the pressure of the gas; V for its volume: T for its temperature R for the universal gas constant (a value of 8.314 joules or mole-degrees Kelvin); and n for a number of moles of gas.

Phase I (New Acquisition)

My conception of the fundamental structure of knowledge acquisition is based on the first phase development of the individual's mental model. The function of Phase I of the model is to ensure the basic acquisition of knowledge by encoding relevant attributes/features of the target concepts and rules, primarily through induction. However, one's prior knowledge should be the basis of initial encoding. Once the relevant attributes/concepts are appropriately represented in the individual's mental model, ensuring operations or transformations should be performed in order to arrive at rule formation/relational patterns. By and large, these two subprocesses are known to work in tandem in laboratory tasks, as well as in practical or knowledge acquisition tasks (Bourne Jr, 1974; Lee, 1982, 1984; and Mayer, 1989), as far as international learning tasks are considered(Medin, 1989; Margolis, 1994). An example of inductive learning can illustrate this phase, as you can see in Table 4. The task is set in the classical concept learning paradigm, but with prepositional instances. Similarly, Boyle's and Charles' Laws, as mentioned earlier, must have been formulated through a series of experiments conducted over a period of a century and a half.

A study conducted by Qin and Simian(1990) recreated data-driven scientific discovery in the laboratory situation. They had 14 university students undertake the task of finding an empirical law, given numerical data of measurements of the distances of the plants from the Sun and the periods of their revolutions around it. This data was equivalent to the data used by Johannes Kepler for his third law of planetary motion. Five of the 14 students discovered the law, while 9 did not. This failure appears to be due to inadequate search strategies and heuristic or nonsystematic and insufficient exploration through instance and rule spaces, while engaging in the rule induction process. (Also, an elaborate inductive learning model with hypothesis generation and testing must have worked in preparing Monod and Jacob's 1965 Nobel Prize-winning discovery of 'gene control' in molecular biology (Dunbar, 1993).)

Using the Brunerian concept identification paradigm, Pazzani(1991) showed that 80 undergraduates took fewer examples(instances) to learn an accurate causal relationship when the test was performed with examples consistent with a general theory of causality, than when the test was performed with similarity-based approaches. The importance of causal knowledge is obvious. Such knowledge is important for our everyday survival, which involves 'prediction', 'planning' and abductive inference. The cumulative and hierarchical nature of cognitive structure (e.g. Newton's 2nd Law) is also demonstrated by think-aloud data (Robertson, 1990).

The above examples are only a few that illustrate the fundamental of new knowledge acquisition, which must provide the foundation for further growth of quality creative ideas. Using a nonexperimental approach with verbal categories and their members, Baughman (1991) showed combination and reorganization as a new knowledge generation process, and argued that it involved three major operations: (1) selecting and using relevant category features, including an organizing rule, (2) grouping or abstracting the features (?) from separate categories by fitting them

Table 4. An Example of the Inductive Knowledge Acquisition Task (Phase I)

Prediction Cases	Outcome
1. A research team at Harvard administered the drug Mixolin to skin cancer patients. The team predicted the purple-colored skin rash as a side effect.	Confirmed
2. Another team at Columbia administered the drug Phoresin to skin cancer patients. The team predicted the purple-colored skin rash as a side effect.	Confirmed
3. Another team at **McGill** administered the drug **Mixolin** to skin cancer patients. The team predicted the blue-colored skin rash as a side effect.	Disconfirmed
4. Another team at **Toronto** administered the drug **Phoresin** to skin cancer patients. The team predicted the **blue**-colored skin rash as a side effect.	Confirmed
5. Another team at **New York** administered the drug **Phoresin** to skin cancer patients. The team predicted the **green-**colored skin rash as a side effect.	Confirmed
6. Another team at **McMaster** administered the drug **Benvin** to skin cancer patients. The team predicted the **purple**-colored skin rash as a side effect.	Confirmed
7. Another team at **Ohio State** administered the drug **Mixolin** to skin cancer patients. The team predicted the **green**-colored skin rash as a side effect.	Disconfirmed
8. Another team at **Stanford** administered the drug **Benvin** to skin cancer patients. The team predicted the **blue**-colored skin rash as a side effect.	Confirmed
9. Another team at **Manitoba** administered the drug **Benvin** to skin cancer patients. The team predicted the **green**-colored skin rash as a side effect.	Confirmed

Question:-
What is the conceptual structure that would compactly represent the nine cases ?

Problem:-
A clinical research team at the University of British Columbia Health Science Center has a skin cancer patient who shows bluish skin rash after some unknown treatments. The team is trying to determine the cause(s) of the rash. What are possible causes ? (Phase I:- Application)

together in an emerging relation (i.e. toward a prototypical exemplar), and (3) assessing the features of the prototypical category members to identify additional members and their features describing the relations. As previously suggested, this type of similarity-based knowledge organization is less useful in knowledge creation than that of theory-driven operation. However, the conception of knowledge acquisition is similar to the one proposed as Phase I.

There is another similar conception proposed by Sternberg and Davidson

(1983) in the context of defining gifted individuals in terms of their 'insight' skills. They proposed that these skills include the following: (1) selective encoding of relevant information in a given context, (2) selective combination of the relevant information in a novel and productive way to form a unified whole, and (3) selective comparison relating newly acquired information to old. The first two of the three skills appear very similar to Phase I, while the third kind skill seems to be a process of comparative and nomological organization of ideas.]]

Phase II (Transfer):

Once any new knowledge is acquired, it cannot and should not remain inert, unless it is meant to be stored as a meaningless piece of information for rote retrieval. Ironically, however, much of what we learn is inert and not utilized during subsequent learning activities, because it is learned in a 'being told' mode outside of any problem solving context (Bransford, Franks, Vye, and Sherwood, 1988). We frequently hear the complaints of university students who fail to retain what they have learned in their course work. This is ironic, since in a way, ensuring successful learning transfer is the business of our educational system. Yet, concerned research professionals in education and psychology lament that the amount of transfer is minimal, if any. This is seen is Detterman (1993), under the treatise "The Case for the Prosecution: Transfer as an Epiphenomenon". Learning would be a hopeless venture in a world with little or no transfer from past to new learning situations. Our implicit theory of transfer as a learning phenomenon, as well as an educational goal, endures despite the lack of evidence that has emerged from empirical research since the turn of the century.

Our implicit theory of transfer includes at least three major variables: (1) what original learning is and how it is completed, (2) how well it was mastered, and (3) how near or far it transfers. Most durable learning does not involve memorizing multiple lists of the surface features of materials, but is a result of the conceptual knowledge acquired through such processes as Phase 1. If the surface features of materials is to be learned, it is natural to calibrate the similarity dimensions of stimulus/response characteristics in predicting transfer between learning and transfer tasks, as was done in the early 1960s. Since learning and transfer tasks can differ in terms of innumerable surface features, the attainment of transfer is unwarranted. This simple logic, if understood correctly, should not surprise us since transfer failures are observed in many studies.

Recently, Reed (1993) advanced a schema-based theory of transfer. By schema, he refers to a cluster of knowledge that provides a skeleton structure for a concept that can be instantiated by the detailed properties of a particular instance. For example, in the context of math or science problems, this skeleton structure is an equation, and instantiation requires replacing general concepts (such as distance, rate, and time) with specific quantities in a particular problem.

First, such a schema theory, in my view, would state that a motivated learner's schema of the knowledge and its accompanying skills, once acquired in a domain/context, is selected, activated, and used for tackling a novel problem. The use or application of the schema entails its novel adaptation of knowledge structure and associated procedures. Second, the ease of such novel adaptation is a function of the availability of a well-learned and articulated knowledge structure, that is, domain expertise (Lee, 1970, 1985; Lockhard, Lamon, and Erick, 1988; Reed, 1993). Further, the extent of transfer success depends on the similarity of learning and transfer task contexts. If the problem tasks are similar within the same domain, either more or less relevant attributes/features than those of the example schema need to be formed for adaptation (e.g., equation). If there are isomorphic problems across different domains, it is necessary to find the correspondence between rule/structural patterns and to represent differences at a higher level of abstraction to establish the isomorphism. It is noteworthy that, as Gick(1986) argued, when learners have no relevant domain-specific knowledge, they may have to resort to the use of heuristics, such as the means/end analysis espoused in Newell and Simon's (1972) search-space framework.

Demonstrating inter-domain transfer, relative to intra-domain transfer, has been a major challenge to researchers. In order to ensure inter-domain transfer, researchers have relied on the use of an analogical transfer mechanism. For example, Bassok and Holyoak (1989) had two groups of high school and college students learn algebra word problems involving the equations of arithmetic progressions (algebra subjects) or physics problems involving constant-acceleration (physics subjects). Each group was given 3 pretests of the same content domain. Upon mastery of the base domain material, the group were given 3 post-test problems from the same domain, and then given 3 transfer-test problems drawn from the other domain. The test problems used differed only with respect to their content and were matched in pairs in terms of their underlying concept structure. Robust transfer was found from algebra to unfamiliar but isomorphic problems in physics, but no transfer was observed from physics to algebra.

Why does this asymmetrical cross-domain transfer occur? Since the physics subjects' did not expect to use an inter-domain isomorphic relationship, they failed to recognize its existence. Besides the importance of the subjects' task perception, the attribute/feature structure of the constant-acceleration rule may be complex enough to require more instantiation exercise for rule mastery. In this regard, Bassok (1990) and Bassok and Holyoak (1993) pointed out that the abstraction of a higher level inter-domain similarity of isomorphic concept structures can be hampered by incompatible attributes/features in **Phase 1** (e.g., psychological intensive vs. extensive attribute values: *speed vs. weight*). Alternatively, the content-specificity of physics may simply prevent spontaneous transfer isomorphic problems with non-physics content. Hence, the concept of transfer is still 'on trial' and a compelling defense should be presented.

The Creative Transfer Process and Its Constraints

Earlier, I ventured a definition of the "creative process" as and inductive leap which combines ideas from across different domains. Surely, the process of combining ideas cannot be meaningfully carried out by the blind induction of elementary data. I have offered two possible sources for the failure of inter-domain transfer from physics to algebra concepts, as reported by Bassok and Holyoak (1989): (1) recognition (perceptual) failure of the subject and (2) the intrinsic nature of incompatible inter-domain task structures.

By now, some, if not all of you, may be wondering what these discussions of knowledge acquisition and intra- and inter-domain transfer have to do with "the creative mind". Now that I have discussed what I mean by the prepared mind in terms of knowledge and skills acquisition, as well as transfer potential, I would like to explore how the prepared mind works to solve ill-defined problems, that is, creative problem solving. Creative problem solving obviously requires the extraordinarily insightful application of prior knowledge and skills on the part of the individual. This is referred to as "creative transfer", which is diagrammed in Figure 2.

A great many creators attest that creative transfer presupposes fundamental knowledge and skills. A central question here is how creative transfer takes place. We need to make this construct more tractable in real world terms. Otherwise, we run the risk of trivializing it. **Creative transfer** refers to the creation of novel and original, and further socially valued solutions to initially ill-defined problems by actively and spontaneously reorganizing and restructuring seemingly unrelated cross-domain knowledge and skills. In addition to the example of the invention of the kinetic theory of gases, another well-known example of restructuring or integration of inter-domain knowledge and skills is Watson and Crick's discovery of the DNA's double-helix structure. It required a thorough understanding of biological concepts and X-ray diffraction techniques that had to be combined and re-organized.
Ultimately, the notion of creative transfer in research and development ought to be constrained, so that the process of reorganizing and restructuring (Vosniadou and Brewer, 1987; Vosniadou, 1989 for the process of theory change) knowledge bases is linked to the level of creative contributions.

The level of the various novel contributions may be categorized into two classes (Ghiselin, 1963), *major and minor* contributions. A major contribution is the product of the cognitive process through which an individual generates new ideas or understanding, which is used in solving a variety of problems. A minor contribution is based on the process through which the individual extends existing understanding to solve limited, but still significant problems (Mumford and Gustafson, 1988). The examples of scientific discoveries given earlier, namely, the invention of the

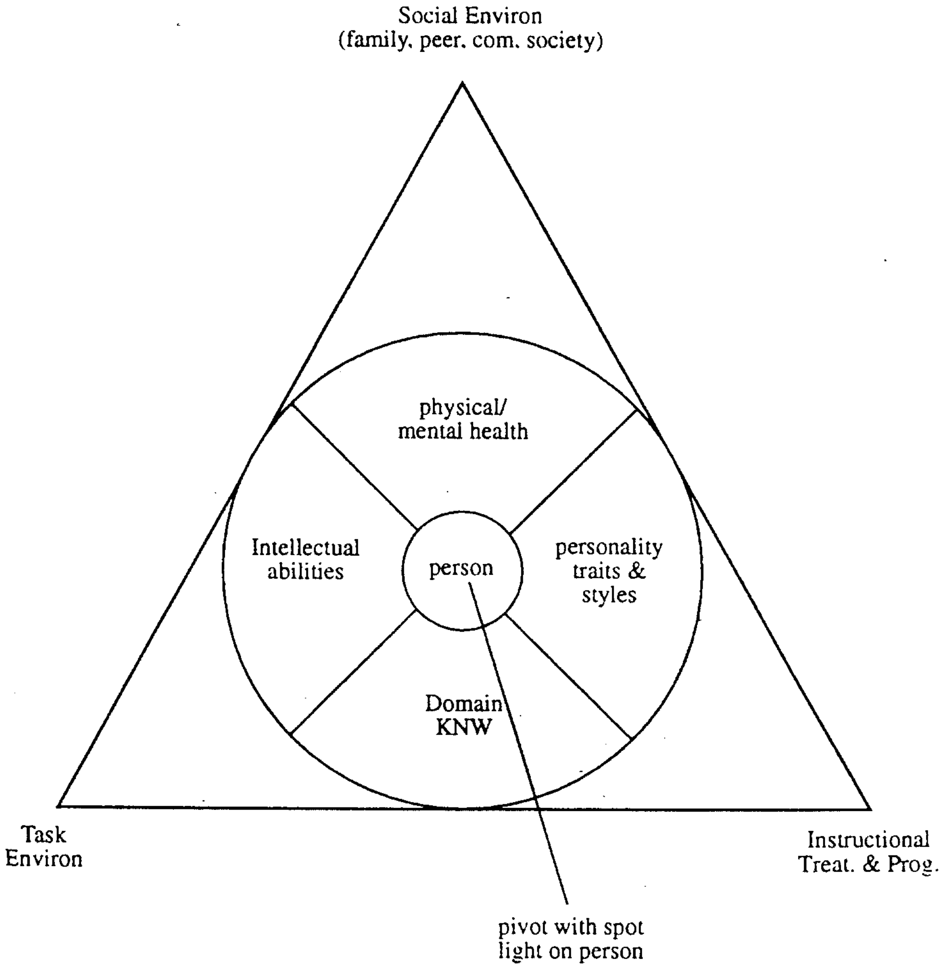
Social Environ
(family, peer, com, society)
physical/
mental health
Intellectual
abilities
person
personality
traits &
styles
Domain
KNW
Task
Environ
Instructional
Treat. & Prog.
pivot with spot
light on person

fig2

kinetic theory of gases, Monod and Jacob's discovery of gene control, and Watson and Crick's discovery of DNA structure, reflect cognitive transfers based on the restructured integration of a major kind.

In the context of the creative transfer process for the kinetic theory of gases, the existing empirical knowledge-base of Boyle's and Charles' Laws provided the necessary components for Avogadro's Law to evolve, and, at the same time, pointed to a missing piece of the entire puzzle. This puzzle was solved by generating a higher level abstraction based on the laws of motion as well as restructuring inter-domain knowledge bases and skills. This resulted in the universal gas law.

Transfer Constraints

Since it is not certain when one's creative activities will come to fruition, it would be useful to determine the conditions under which the ultimate creative achievement of problem solving is likely to be realized. Let me outline four types of conditions that can constrain creative fruition: *(1) domain -specific knowledge, (2) degree of expertise, (3) tacit/implicit knowledge, and (4) effective cognitive skills/style.*

The first of these constraints, an individual's domain-specific knowledge, is absolutely essential for spontaneous creative transfer. In contrast, information of an episodic nature cannot be the foundation of mainstream creative activities. From a developmental learning perspective, Brown (1990) claimed that even children as young as 1 to 3 years of age, transfer on the basis of deep structural principles rather than perceptual features when they have access to the requisite domain-specific knowledge. Further, she argued that a search for causal explanations (knowledge) is the essential element of meaningful learning; that is, the basis of broad understanding, of wide patterns of generalization, and of flexible transfer and creative inferential projection.

In another study (Novick and Holyoak, 1991), it was found that once college students learned a mathematical schema as a potential prototypic source for analogical transfer, the induced schema coexisted with referent problems and facilitated later transfer. This suggests that a math domain expertise is a significant predictor of transfer, but that general analogical reasoning ability is not. Using high school and college students, Bassok(1990) studied the transfer of math problem-solving procedures learned in content-rich quantitative domains (e.g., physics, finance) to isomorphic algebra word problems dealing with other contents. Spontaneous transfer to isomorphic problems across domains occurred when basic variables (concepts) were compatible (e.g., speed and typing rate), but transfer did not occur when the basic variables were not compatible (e.g., speed and salary). If we interpret the findings in terms of the intensive vs. extensive nature of the variables, which are the building blocks of the contextual structure of the problem domains, we must acknowledge the importance of one's in-depth semantic knowledge of the domains concerned.

The second of these constraints, the level of one's expertise in a particular domain, as related to the requisite nature of domain-specific knowledge, is one of the most potent determinants of creative transfer. This expertise is manifested as productive restructuring, that is, the positive impact of prior learning on subsequent learning. The level of expertise can affect the quality and diversity of problem definitions. For example, in the domain of physics problems, Chi, Glaser, and Rees (1982) found that a novice's lack of a knowledge base limited the generation of inferences and relations not explicitly stated in the problem. In contrast, an expert's developed knowledge allowed him to elaborate upon the problem by bridging the gap between novel problems and previous experience. It is also possible that the expert's familiarity with a particular approach or domain, cause failure to consider alternative approaches (Barnsford and Stein, 1984). This is reminiscent of the phenomenon called "functional fixedness".

Furthermore, Novick (1988) found that her college experts in math showed more spontaneous positive transfer than novices, when given a target problem and analogue problems that shared similar deep structures, but that had dissimilar surface features. Also, it was found that her novices showed greater spontaneous negative transfer than experts, when given the target problem as well as a distractor problem which shared similar surface features, but had different deep structures. In other words, experts are more likely to define the similarities between problems in terms of deep structures rather than surface features; whereas novices are vulnerable to distracting surface similarities. How can experts function when given a novel problem for which they lack domain-specific knowledge? Schraagen (1993) showed that the lack of domain knowledge is compensated for by using abstract knowledge structures and domain-specific heuristic strategies. The quality of their solution, however, is considerably lower than that attained by experts who were familiar with the type of problem to be solved.

Each individual continually builds two broad classes of knowledge: (1) an implicit and tacit knowledge base and (2) an explicit knowledge base. **The third** of the constraints I mentioned earlier, the implicit and tacit knowledge base, is acquired through incidental learning. This incidental learning is not necessarily a result of conscious cognition, is not clearly articulated into structure, is informal and not brought into public scrutiny, and is enriched through one's inductive experiences in the context of occupational/professional practices. In contrast, the explicit knowledge base can be defined by a set of features opposite to those listed above. In this regard, Reber (1989) made three convincing claims: (1) a tacit knowledge base acquired via implicit learning is abstract and representative of the structure of the environment; (2) such a base is optimally acquired independently of conscious efforts to learn; and (3) such a base can be used implicitly to solve problems and make accurate decisions about novel stimulus environments.

Kaha (1983) made the related observation that a creative individual uses primary processes (unbound by logic), which are either unconscious or pre-conscious, in such a way that the target material comes to an individual's awareness, while the manner in which it came to awareness remains unknown. Although primary and secondary (rational thought) processes do not recognize one another, the mind operates synchronistically at both levels to create a new conscious perspective by merging both processes. It is this new conscious perspective that we label intuition or insight. I propose that it is this *extra-domain* of implicit/tacit knowledge that provides a rich source of new insight in the event of a cognitive stalemate. This insight facilitates a breakthrough for intra- or inter-domain knowledge reorganization and restructuring.

Finally, the productivity of cognitive operations for creative transfer is maximized by the individual's serendipitous and spontaneous intellectual style, when equipped with analogical strategies and effective heuristics.

Serendipity - Serendipity is not viewed here as stemming from purely external chance, but instead from general exploratory activities with curiosity and persistence (Austin, 1978). Chance favors those in motion and the prepared mind that has specific knowledge and particular sensitivity.

Spontaneity - Spontaneity is an emergent attribute of the well prepared mind, as well as a result of and an actively inquiring interest in an intellectual task. Creative transfer is contingent on one's spontaneous access to the task at hand. In this regard, Stein, Way, Benningfield, and Hedgecough (1986: Experiment 3) found that problem-solving performance under spontaneous transfer conditions was unrelated to whether or not the provided relevant clues could be recalled prior to the problem-solving task. In contrast, problem solving performance under informed conditions was highly related to the recall of the problem clues. Stein (1989) questioned the effectiveness of problem clues in solving more complex or natural problem-solving tasks that would require creativity. The utility of such clues would diminish as the number and complexity of the transfer task increase, especially under uninformed and spontaneous transfer conditions (Stein, 1989, Experiment 2). Thus, spontaneous transfer was seen to involve an implicit knowledge activation process that did not rely on the recall of problem clues.

Analogy - Innovations in science and art often arise as a result of analogical thinking (Johnson-Laid, 1989). The creation of a profound analogy is unlikely to depend on pre-existing rules of mapping between the source and target domains. Vosniadou (1989) espoused the use of intra- and inter-domain analogies to solve problems about an unfamiliar target system. Futhermore, the initial acquisition of the knowledge base can be used for dealing with increasingly complex structural relations. Although critically limited by the semantic information included in the knowledge base, analogical reasoning can act as a mechanism for enriching, modifying, and radically restructuring the knowledge base itself.

Heuristics - A majority of the inferential problems we encounter in life can be resolved by means other than the use of a certain set of algorithms

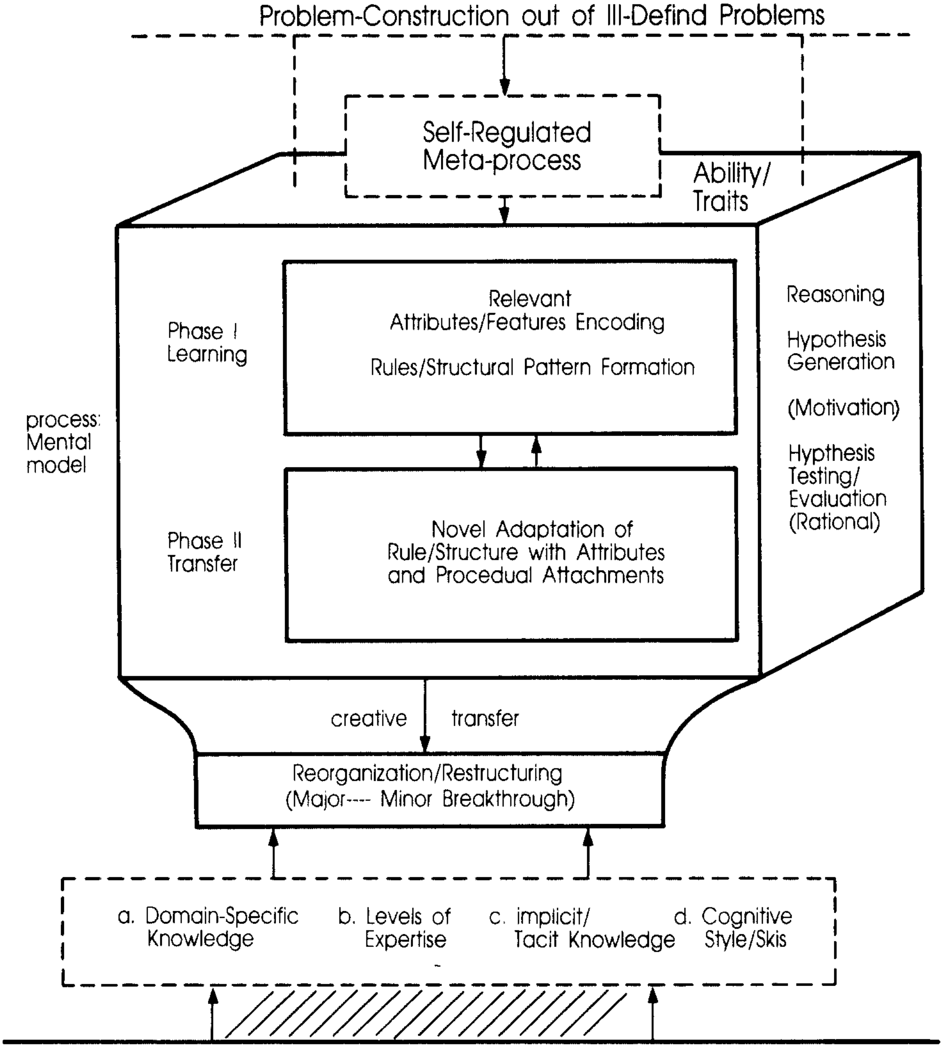

Fig. 3 Ill-Defined Problem Solving Task/Context

that are methodically followed in a step-by-step manner. Some insightful people invent their own data-driven, theory-driven or mixed heuristics to solve inference problems, through the divergent production of novel ideas (Hayes, 1989). If we want to ensure to facilitation and maximization of cognitive transfer, the constraints identified thus far should be given serious attention.

Reasoning Mechanisms and Self-Regulated Meta-Processes

Thus far, I have described the conceptual process model of acquisition and transfer by the two phases. I have also illustrated how to extend this model to creative transfer applications. However, there are still two critical questions I must address: (1) what are the basic reasoning mechanisms working throughout basic or higher levels of knowledge acquisition and transfer? and (2) what are the factors underlying an individual's self-regulatory behavior? The two questions are basically concerned with reasoning and self-regulatory processes, whose components can be diagrammed in Figure 2.

Before an attempt to answer these questions, it would be highly instructive to examine Clement's (1989) case study report that was based on a physics professor's "think-aloud" protocol. It was obtained during problem-solving ("spring and wheel" problems). Clement made careful and penetrating observations of his subject's creative reasoning in terms of eight features. A summary of these features is listed in Table 5.

The first question, which concerns the *basic reasoning mechanisms,* can be answered by examining the hypothesis generation and evaluation operations employed during the explanatory model construction described in Clement's case study. These operations include: (1) generating a new hypothesis via non-inductive means in the absence of new empirical information; (2) successive refinement of the hypothesis, involving repeated cycles of generation, evaluation, and modification or rejection rather than a convergent series of deductions or inductions from observations; (3) hypothesis evaluation as an inherent part of formation, through rapid or slow dialectic interplay between two processes: and (4) the development of a convincing explanatory model hypothesis which can lead to the formation of an empirical law hypothesis. In other words, the final explanatory model of *the polygonal coil*

Table 5. Eight Features of Creative Reasoning Think-Aloud Protocols Provided by a Physics Professor Clement (1989) Summarized:

1. the evidence of insight leading to a "flood of ideas";
2. the invention of a new model of hidden mechanism in the spring (torsion, lack of cumulative bending);
3. desire to ask "why" of an explanatory model;
4. a remarkable persistence in this quest in the face of recognized internal inconsistencies and repeated failures;
5. playful and uninhibited inventiveness in producing conjectures and modifications of the problems ;
6. willing to criticize and attack the validity of his own conjectures ;
7. alternating between generative and evaluative modes of scientific thinking ;
8. willing to consider "risky" analogies, such as the double-length "spring" and "bending rod", criticizing his ideas and keeping faith in himself as a self-correcting system, thereby allowing him a freer hand.

with torsion supports the empirical law hypothesis that, with other factors being equal, wide springs will stretch more than narrow spring.

Three additional points may also be relevant to this question: (1) a significant improvement comes from a breakthrough which is either based on overcoming barriers or a relatively sudden insight rather than from a pure 'eureka' event, (2) spontaneous analogies are generated and used as the rough initial predictive model; and (3) divergent and creative processes represent a significant departure from the more systematic processes of hypothesizing.

Some answers to **the second question,** which concerns *self-regulatory processes,* can be found in **5 out of the 8 features listed in Table 5,** which were displayed during the creative model construction. These features are: desire to ask why, persistence, inventiveness, self-criticism, and cognitive risk-taking; all of which reflect the psychological attributes of cognitive motivation.

Hayes (1989) characterized what creative people are like. The characteristics he identified included: (1) hard work, (2) a disposition to set their own agenda and take independent action, (3) pursuit of originality, (4) demonstration of more flexibility compared to others, but (5) similar IQ and school grades as others, with age and education controlled. Having identified these characteristics as significant, Hayes proposed that creative performance has its origin not in innate cognitive abilities, but rather in the motivation of the creative person. Over time, this motivation has cognitive consequences, such as the acquisition of large bodies of knowledge, that contribute in a critical way to creative performance; *but the origin is in motivation, not cognition.*

It is difficult to disprove the main thesis of Hayes' proposition, since it can potentially be interpreted as circular argument, which would trap us in a counterproductive debate, I agree, however, on the importance of motivational variables, because even a creative individual's efforts to construct a final explanatory hypothesis model cannot be sustained without persisting efforts (Matson,1990; Sapp, 1992). The activity of hypothesis construction in an ill-defined problem situations cannot begin in the absence of the genuine interest and motive. At this point, we must presume that an individual has a self-regulatory autonomous mind (Armbruster, 1989; Pesut, 1990; Bouffard-bouchard, Parent, & Larivee, 1993), which is often called an executive controller with metacognitive orchestrating skills. This executive controller must work on goal setting, planning, monitoring, and evaluating feedback, etc. For example, it can even monitor one's level of drive satisfaction, as in the phenomenon, called "delayed gratification". Even a well-crafted engine cannot run smoothly and effectively unless gas and various lubricants are adequately supplied and properly monitored. An individual's continuing interest and drive to attain his set goal provides the fuel required to power his **'cold'** cognitive engine and keep it **'hot'** enough to carry his creative potential towards socially valued achievements.

In closing, I hope that the assessment and prediction of creative potential and the specific programs used to nurture them can be re-examined from the perspective I have presented. I had made the cognitive learning perspective as the subtitle of my talk,

as hinted in Figure 1. I believe that, given a threshold level of intellectual talent, an individual's inner motivation will allow him to bring his creative potentials up to the pinnacle of human achievement. Thank you.

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