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問題解決模型：變異與選擇建構論的觀點

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摘　要

本文嘗試以「變異與選擇建構論」的觀點，來提出一個廣泛適用的問題解決模型，著重於理論解釋範圍的擴展。當一個開放的互動系統追求某個目標並受到某些束縛時，它就面臨一個「問題」。演化是透過變異、選擇與保存所形成的自我組織歷程，也是一種必要而基本的問題解決歷程，其中生物層次的演化只是一種特例，用於解決生存問題，而心理層次的知覺、閱讀及溝通等歷程，也可被模擬為解決認知或社會互動問題的微觀演化歷程。此外，創造發明、科學探究及藝術創作歷程，也可被視為一種問題解決歷程，並且是一種社會文化層次的演化歷程，因為在創造、發明或探究的歷程中，個體（或甚至一個群體）通常都具有追求的目標，受到某些困難與限制，並透過變異、選擇與保存的歷程，解決其問題。所以，本文的觀點是建立在知識演化論與根本建構論的基礎上，嘗試提出一個跨越生物演化、認知心理及社會文化層次的模式，描述最基礎的問題解決歷程。然而也有學者認為：「盲目變異」的解題效率太差，不可能是人類解決問題所使用的方式。但若將問題解決歷程當中產生「變異」的機制視為「盲目變異」以某種比例混合「植基於先前演化基礎的變異」，則「變異與選擇建構論」的觀點幾乎可以模擬所有的問題解決歷程。

關鍵詞：變異與選擇、建構論、問題解決、創造、演化知識論

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Problem-Solving: Perspectives from the Variation and Selection Constructivism

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Abstract

The current paper aimed to apply a general form of explanation, based on the evolution mechanism of variation and selection, to model the iterative problem-solving process involved in biological, psychological, and social/cultural levels. A "problem" was defined by two necessary conditions: a goal for an interactive agent and some constraints on the process to obtain the goal. Evolution was defined as a general self-organizing process through the retention of selection of variation. A general model of problem-solving process was proposed and showed the possibility that it can be applied to explicate the cognitive process of perception, reading comprehension and communication. In addition, the model was also applied to illustrate creativity, scientific inquiry, and art production on the social/cultural level. A potential challenge to this model is the idea that blind variation is inefficient for problem solving so that human problem solving obviously employs sighted variation. This challenge can be avoided if we admit that evolutionary achievements put constraints on variation, reduce problem space, and iteratively raise the probability of successful problem solving. We should also aware that the efficiency of solving a particular problem depends on the degree of novelty of that problem. A completely novel problem requires blind variation of trial-and-error for solving it, while a completely old problem calls for sighted variation. Most problems are somewhere between the two extremes and are to be solved by a combination of different proportions of blind and sighted variation. The current model has important implications for cognitive psychology, philosophy of science, epistemology, and education.

Key words: variation-and-selection, constructivism, problem solving, creativity, evolutionary epistemology

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Variation and selection is a general and powerful form of explanation, of which biological evolution turns out to be an instance. As Bickhard and Campbell (in press) pointed out, such a form of explanation is necessary to explain constrained processes. They argued that,

> "In general, variation and selection is almost always the appropriate form of explanation when issues of fit or satisfaction are involved, especially concerning regularities of such fit or satisfaction (Bickhard & Campbell, 2003: 272)."

Such a form of explanation has been extended to several other domains and applied to many other levels. For example, Hull, Langman & Glenn (2001) made efforts to provide a general account of iterative variation and selection processes applicable to the adaptive phenomena that arises in biological evolution, immune response, and behavior. However, in agreement with Cziko's (2001) position that internal goals rather than external behaviors are varied and selectively retained, the current paper aims to provide such a form of explanation applicable to multi-levels of problem-solving processes involved in biological, psychological, and social/cultural levels. The iterative processes to be illustrated in the current paper have varies time scales, ranging from a few mini-seconds to billions of years, indicating micro-evolutionary processes within macro-evolutionary processes.

Definition of a "Problem"

A problem is a system composed of two necessary parts: goals and constraints. In one particular problem, there may be only one goal or multiple goals, which are interdependent or in conflict. Living organisms, including human beings, are goal-directed interactive systems (Campbell & Bickhard, 1986). For any goal of an interactive system, there always are some sorts or degree of constraints. The types and degrees of constraints are different from individuals to individuals and from species to species. For example, to get a pencil on the table may be an easy problem for person A but a difficult problem for person B, who is handicapped, and even more difficult for a bird.

The above definition of a problem is intended to be broad in general. Whenever a living organism encounters a situation where he is interactive with his internal subsystems or with external environments toward a goal with some constraints, he is facing a problem. All of the following organisms encounter a problem situation: An ant tries to drag a piece of cake much bigger than itself; a rabbit tries to escape from a hunting eagle; an eagle tries to catch a rapidly escaping rabbit; a chimpanzee tries to get the banana hung up on the roof; a writer tries to finish a new book; a scientist tries to resolve a theoretical conflict or to test an empirical hypothesis; an artist works hard to produce a satisfying painting; a musician tries to compose a fascinating music; a political leader tries to campaign for state independence; a cop tries to find out the true murder in a crime; student tries to answer the questions in a test; a checker player tries to beat his competitor. All of those individuals are engaged in an interactive process toward a goal (or some goals) with some constraints. Therefore, they are involved in a problem-solving process.

There are two kinds of goals: explicit and implicit ones (Campbell & Bickhard, 1986). Explicit goals can be known about or reflected on consciously at a meta knowing level of the interactive system. Implicit goals are implied by the interactive system but not known about by it. To write a poem is an explicit goal for a poet, while to survive on the earth is an implicit goal for a species. There are also two kinds of constraints: explicit and implicit ones. Explicit constraints are internal indicators of the external constraints and can be known about or reflected on consciously at a meta knowing level of the interactive system. Implicit constraints are external constraints to be interacted with or internal indicators of constraints but cannot be consciously known about. The rules of rhythm and numbers of words to be used in certain style of poetry are explicit constraints for a poet, while natural selection pressures are implicit constraints for a species.

From this viewpoint, it can be said that biological evolution is also a problem-solving process, in which a species is a problem solver.

Evolutionary Problem-Solving Process (EPSP)

Evolution is defined as a general self-organizing process through the retention of selection of variation, as shown in Figure 1. The dynamic, iterative, bootstrapping, and self-organizing process starts in a system of problem situation (system A), which is encountered, discovered, or defined by a second system (system B), which in turn produces variation to be selected by a third system (system C). If the variation fails to pass the selection, then the second system must go back to the problem situation (sometimes to redefine the problem) and/or to make another variation. If the variation succeeds to be selected, it is retained by a system (system D) and can be reproduced to solve effectively or ineffectively the same problem or a novel problem in the future. After more and

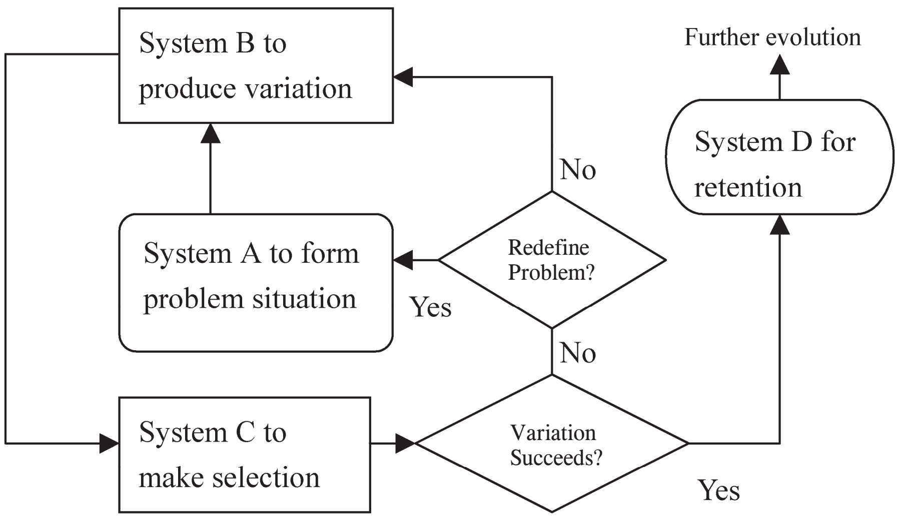

Figure 1. A general model of EPSP.

more iterations, successful variations can be accumulated, combined, and re-structured in the system D, which can exert powerful influences and constraints on variation in the future. The influence of system D on system B can be facilitation as well as limitation. The reorganization of system D is also possible when its limitation on system B decreases problem-solving efficacy and becomes explicit to system B.

In this model of evolutionary problem-solving process (EPSP), Campbell's (1960) blind-variation-and-selective-retention theory is still at the core. However, for the current model to be general and to avoid some criticisms from several anti-evolutionists, the concept of variation in this model includes "blind variation" and "variation based on prior evolution," which will be explicated later.

The four systems in this model should not be viewed as four completely separate systems on the same plane. They may have overlapping elements. For example, constraints of a specific problem in system A are also elements of system C, which may includes additional elements of more general selection pressure in bigger context. Besides, some of the systems may be subsystems of the others. For example, system B could be subsystem of system C, while system D could be subsystem of system B, depending on the level and context on which this model is applied.

Table 1 presents the biological, psychological, and social/cultural levels on which the above four systems are particularized. Living organisms without central nervous system (e.g., plants) are capable of gaining benefits from biological evolution. Living organisms with a central nervous system (including a memory system) are benefited by both psychological and biological evolution, but gain little facilitation from social/cultural evolution unless they have external symbolic systems and media to form convention and culture, which preserves successful variation from psychological evolution. Human beings are benefited by EPSP on all three levels.

Table 1. The four systems in Figure 1 to be particularized on three levels.

	System A	System B	System C	System D
Biological level	A survival situation	A species to produce gene variants	A natural system to select genes	A gene pool to preserve successful genes
Psychological level	A particular problem	The hypothesis-generating process	An informational context to select hypotheses	A belief system to preserve successful hypotheses
Social/cultural level	Problems	Persons to produce memes	Social systems to select memes	Culture to preserve successful memes

EPSP on the Biological Level

When systems A, B, C, D in Figure 1 are respectively replaced by a survival situation, a species, a natural selection system and a gene pool, we get a model of the evolutionary process on the biological level, as shown in Figure 2. Since parts of the survival situation are stable, reproduction of the prior successful genes can promote the problem-solving efficiency and raise the survival probability. However, some parts of the problem situation are unstable and some parts are not-yet-solved. Therefore, the recombination of the prior successful genes, producing new patterns of genetic structure and novel functions of the individuals, gives the possibility of solving the new parts of the problem situation. Gene mutation is also helpful if only the mutant is not too novel to communicate with its species. Variation due to mutation is totally blind. Variation due to recombination is partially blind and partially based on prior evolutionary achievements. Variation due to replication is totally based on prior evolutionary achievements.

Both blind variation and variation based on prior evolution are active in the sense that genes do not directly receive information from the outside environment but construct information inside the organism and try it out on the natural selection context. The

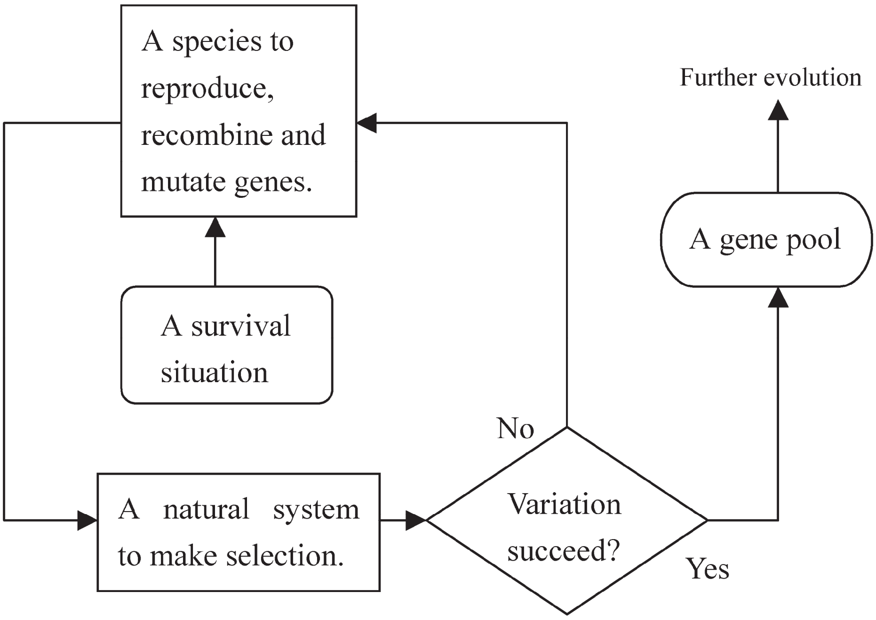

Figure 2. EPSP on the biological level.

information constructed in the gene is a kind of hypothesis in nature. Through the trial-and-error process or the implicit "hypothesis-testing" process from generation to generation, the constructed information is replaced by more and more viable "hypotheses" so that genes indirectly "know" the environments to a certain degree. This process is a Darwinian rather than a Lamarckian one. Such a kind of explanation is prompted by evolutionary epistemology (Campbell, 1960, 1974) and radical constructivism (von Glasersfeld, 1995).

EPSP on the Cognitive Level

When systems A, B, C, D in Figure 1 are respectively replaced by a particular problem, a hypothesis-generating process, an informational context for selection and a belief system for retention, we get a model of the evolutionary process on the psychological level, as shown in Figure 3. On this level, a problem can be encountered, discovered or defined/redefined by a knowing agent. Specifically speaking, manifest problems such as those on students' tests are to be encountered. Hidden problems such as a logical inconsistency implied by a scientific theory are to be discovered. Ill-defined problems such as most social problems sometimes need many times of redefinition in the EPSP. Any problem, no matter how it is encountered, discovered or defined, has to be perceived or interpreted by the knowing agent. Both perception and interpretation of the problem situation are active cognition and are sub-evolutionary processes within the evolutionary process in Figure 3.

For solving a problem, the knowing agent must actively construct hypotheses as possible solutions and put those hypotheses to be tested against his/her informational context. The information relevant to the problem in hand could come from individual

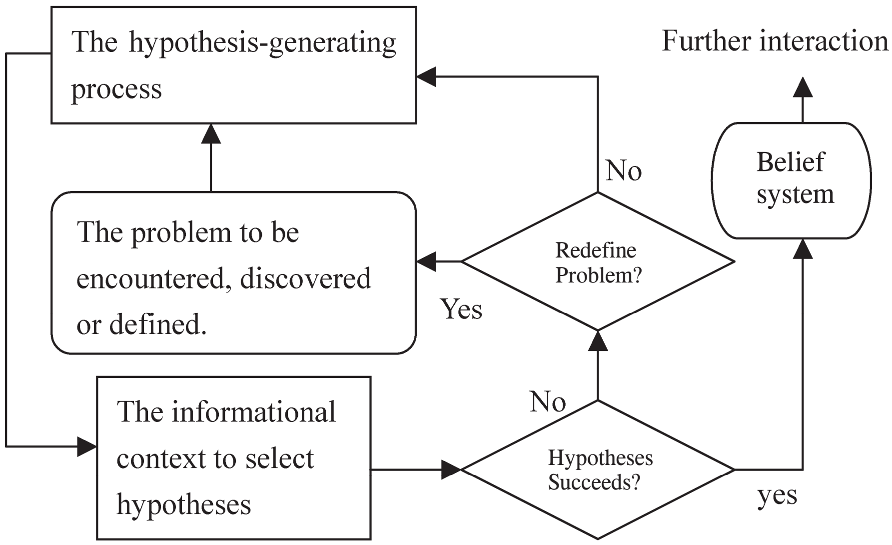

Figure 3. EPSP on the cognitive level.

experience, empirical evidence, theoretical background, metaphysical consideration and even emotional/motivational consideration, although the selection based on some particular information could be more rational than the selection based on other information. If the hypothesis failed to be selected, the knowing agent will go back to the problem for re-interpreting the problem situation or go directly to construct alternative hypotheses. If the hypothesis is successfully selected, it will be retained in the knowing agent's belief system. Therefore, the belief system develops and grows into more and more complex system.

It is a distinctive feature on the psychological level that the problem situation, the variation process, the selection context, and the belief system constitute four internal subsystems of the knowing agent. The knowing agent detects errors through conflicts among information constructed through the four subsystems. No information comes directly from the outside. Information can only be constructed internally through micro and macro evolutionary processes and can be wrong.

Some concrete examples of the EPSP model applied on the cognitive level will follow.

Perception as an EPSP

The following two examples demonstrate the interactive process between a knowing agent and a visual object, although this process can be generalized to perception about symbols, events, audio signals, social situations, etc. Here is a problem for a person X: "what is it in Figure 4?" He then must construct a hypothesis, which can be "it is a snail." Just as Popper (1976) said, hypotheses are usually proposed in a dogmatic manner before criticized. Now, a schema of a snail in the person's brain must be fitted to the pattern of Figure 4. In other words, the person must try to use the schema of a snail to organize the information of Figure 4 into a whole. The related information includes physical features and their inter-relationships of Figure 4. This fitting process is similar to what Piaget called "assimilation." If the person decides that the schema of a snail can-

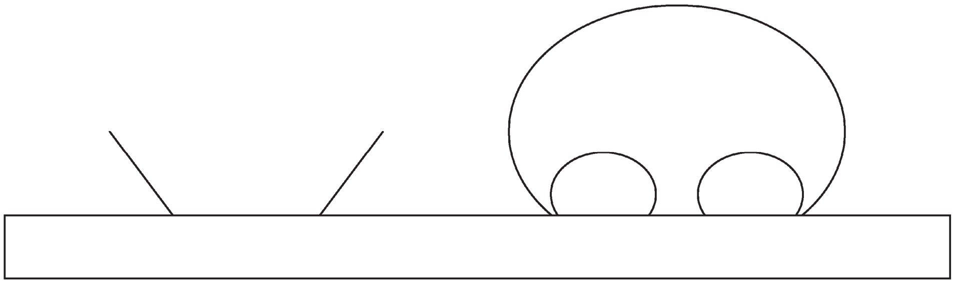

Figure 4. A figure to be perceived.
Source：Redrawn from Osgood（1953: 214).

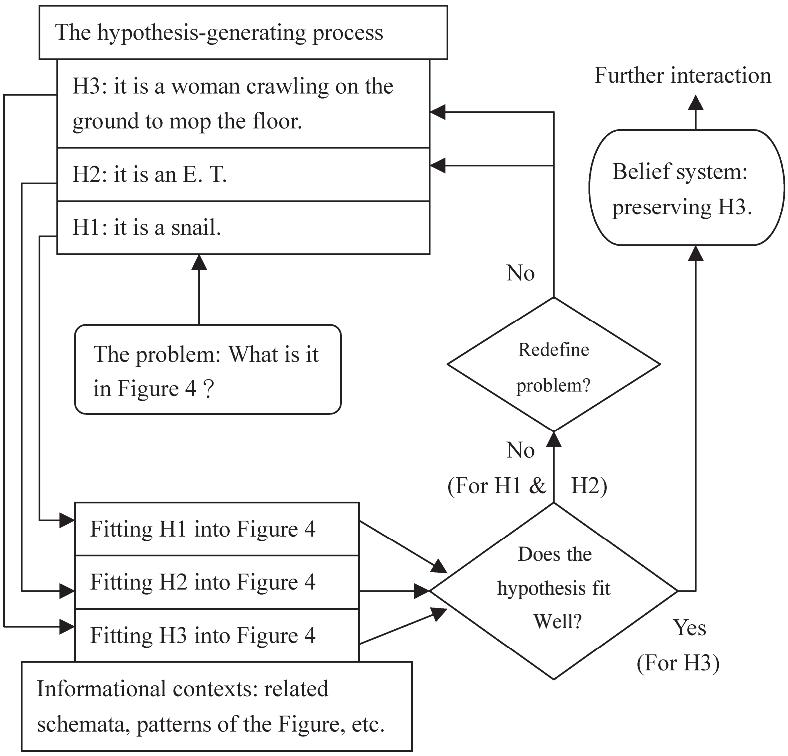

Figure 5. The perceptional process of person X on Figure 4.

not organize the information of Figure 4, then he may go on to try to generate a second hypothesis and there begins another cycle of the hypothesis-generating and hypothesis-testing process. Otherwise, he gives up the problem and leaves the situation. In other words, when the first try of assimilation fails, the person could make an accommodation and construct another hypothesis. This interactive process between the person X and Figure 4 is shown in Figure 5.

According to Figure 5, the second hypothesis constructed by the person X is that " it is an E. T." Unfortunately, this hypothesis is still judged to be unsuccessful by the contextual information of him. Therefore, he goes to the third cycle. The third hypothesis that "it is a woman crawling on the ground to mop the floor" is judged to be adequate and is saved in his belief system. Now the person X could go to another problem situation and continues to be interactive.

Next time when the person X meets Figure 4, he will tend to reconstruct the successful hypothesis, i.e., the third one. After many times of re-encountering Figure 4, the third hypothesis will become a habitual hypothesis and the EPSP will finish in one rapid cycle. That's the reason why people tend to agree that perception is automatic and to ignore the active process. When the habitual hypothesis is challenged or unfamiliar objects are encountered, perception requires a much longer time than usual because the knowing agent needs sufficient time to generate hypotheses and to test them.

The knowing agent's belief system includes successful hypotheses gained from learning and development. It also includes successful pre-assumptions from successful evolutionary results on biological level. When the object, the event, or the signal to be perceived is highly stable from generation to generation, the knowing agent will easily be able to construct a successful hypothesis based on his biological wisdom due to evolution on the gene level. Consequently, the EPSP in perception will quickly close in one cycle and save energy of the knowing agent for another problem-solving process.

The number of the evolutionary problem-solving cycles depends on the judgment of the fitness of the hypothesis. When the judge is the person who proposed the hypothesis, the number of iterative cycles depends on both the perfectionism of the person and ambiguousness of the perceived. Therefore, individual differences are expected to exist. With the same process shown in Figure 5, a different person Y might decide that his second hypothesis fits well, while another person Z might decide that his third hypothesis still fits unsatisfactorily. On the other hand, the more ambiguous the perceived thing is, the more cycles the iterative process requires.

Usually, one particular problem-solving process stops when one successful solution is accepted. However, it is not always the case. At least in the following conditions, some people might construct multiple successful hypotheses: a) to perceive ambiguous objects/events/situations, b) to explore another possibility just for fun, and c) to incorporate alternative successful hypothesis constructed by other persons. An example is provided in Figure 6 and 7.

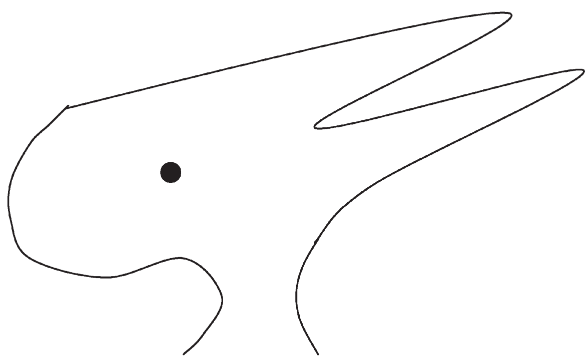

Figure 6. An ambiguous figure.

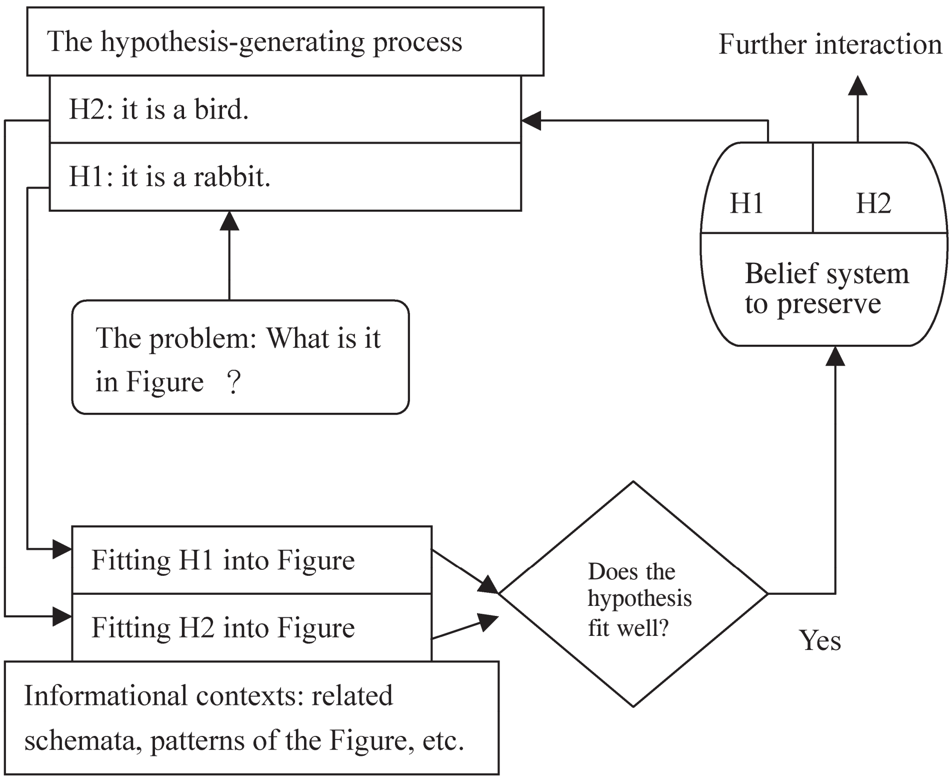

Figure 7. The perceptional process of person Y on Figure 6.

Reading comprehension as an EPSP

Old views about reading comprehension tend to assume that it is a passive process in which the reader receives input information from the writer. Many cognitive psychologists, including schema theorists and constructivists, would argue that the reading process is active and creative. Reading is not to recover the original meaning of the writer; rather, it is to construct meaning out of texts. The meaning of texts is not determined solely by the reader or by the writer. It is co-constructed by both sides.

Table 2. A passage of text with communicational situation to be guessed.

"I have two sons, six and eight years-old." Said A. "All ⋯ right." B replied with some hesitation. "I also have one dog." Said A. "Oh, then I must say 'I am sorry.'" Said B.

A passage of texts is shown in Table 2. In order to comprehend the passage, readers have to guess the communicational situation, using that situation as a schema to organize items of information in the passage. The whole comprehension process of reader X as an example is shown in Figure 8. After reading the passage, this reader began with a hypothesis that person B was doing a census on person A. Using this constructed situation as an "advanced organizer," he tried to read the passage again but he found out that the passage is still not very comprehensible. He constructed a second hypothesis that person A tried to get into a theater while person B was the gatekeeper. He decided to accept the second hypothesis because he was satisfied with the degree of comprehension he obtained by using this working hypothesis as an organizer. However, he went on to construct a third hypothesis, which also turned out to be successful, probably because he just intended to test his creativity or was required by other persons to do so.

Communication as an EPSP

Communication is a complex process and can be analyzed on many levels or from different viewpoints. Table 3 shows a communicational process frequently to occur in the situation where members of a family have dinner together. This process can be analyzed on the individual cognitive level according to Steve's comprehension of his mother's Speech/acts, as shown in Figure 9. In order to understand his mother's speech act, Steve constructed three hypotheses and obtained three times of negative feedback in three iterative problem-solving cycles. He got a positive information feedback and solved the problem in the forth cycle. This process is basically a holistic perception of audio and visual signals. It is also highly similar to reading comprehension process except

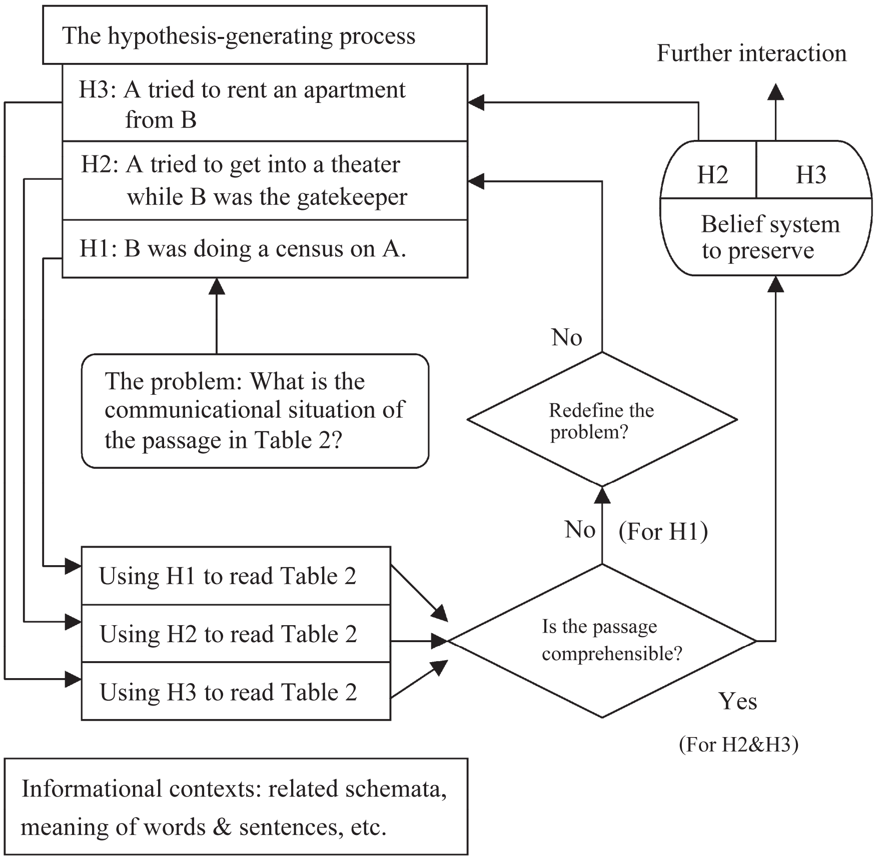

Figure 8. The comprehension process for reader X to read the passage in Table 2.

that not only texts but also emotional expressions and acts can serve as informational contexts to select hypotheses.

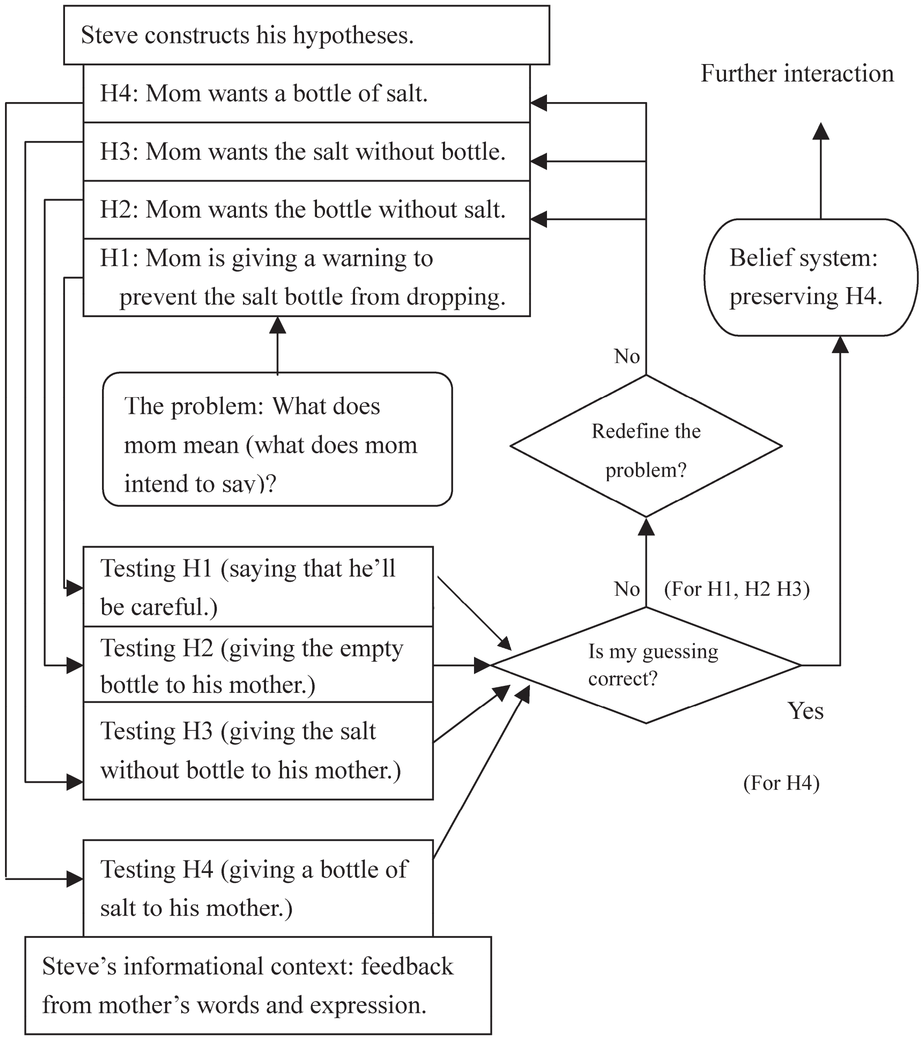

Figure 9. The evolutionary communicational process in Table 3 analyzed from the view of Steve's cognition.

Table 3. A puzzled communication for Steve.

(Members of a family have dinner together) "Salt bottle is on the edge of table." Mother said to little Steve. "OK, I'll be careful." Said Steve. "What I want to say is 'Pass the salt bottle to me, please!'" Steve carefully poured out the salt to a bowl and gave the empty bottle to his mother. "I don't want the empty bottle. I want the salt." Said mother, Carried a funny smile. Steve gave a hand of salt to his mother with a puzzled face. "Put the salt in the bottle and give the whole bottle of salt to me, please!" Said mother. Steve poured in the salt to the bottle and gave a bottle of salt to his Mother. "Thank you!" Said Mother.

The communicational process in Table 3 can also be analyzed at the social/interpersonal level. This level of analysis reveals power relationships between Steve and his mother. As shown in Figure 10, Steve proposes hypotheses while his mother makes se-

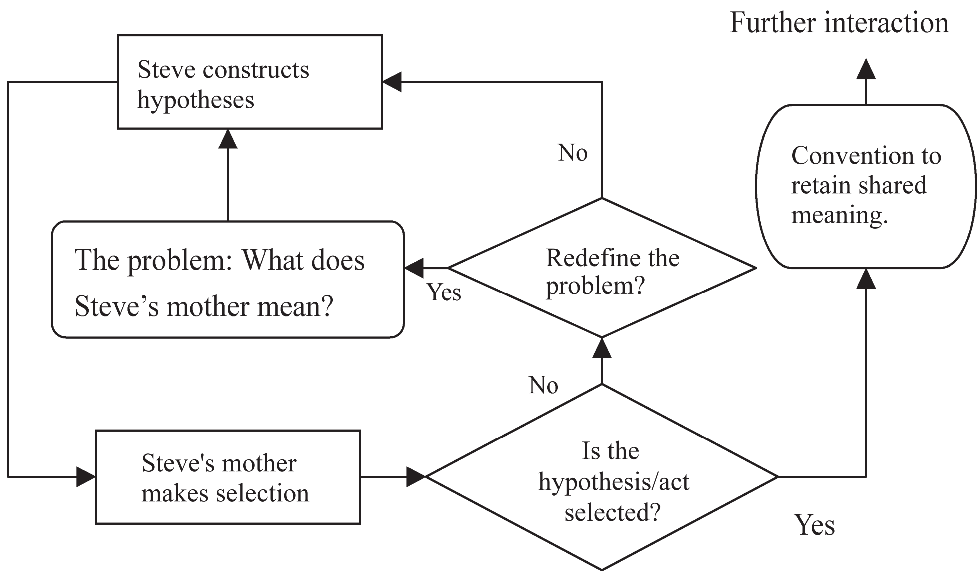

Figure 10. The evolutionary communicational process in Table 3 analyzed from the view of instruction: a non-symmetric communication.

lection. This is a non-symmetrical communicational process usually occurring between parents and children or between teachers and students. In a more symmetrical communicational process, where the participants have roughly equal power, all partners can make mutual selection, as shown in Figure 11. Regardless of power relationships, all communicational processes are involved with mutual guessing, mutual selection, and mutual agreement of meaning (i.e., shared meaning to be retained in convention).

Viewed from a social/psychological perspective, when two partners are involved in a communicational process, a model of double EPSP is needed. For example, person A initiates a communication. Based on his first hypothesis (H1), person A produces " Speech/act 1," which in turn induces person B to construct the second hypothesis (H2), which in turn serves as the basis for B to produce "Speech/act 2," which in turn induces A to construct the third hypothesis (H3), etc. For the efficiency of communication,

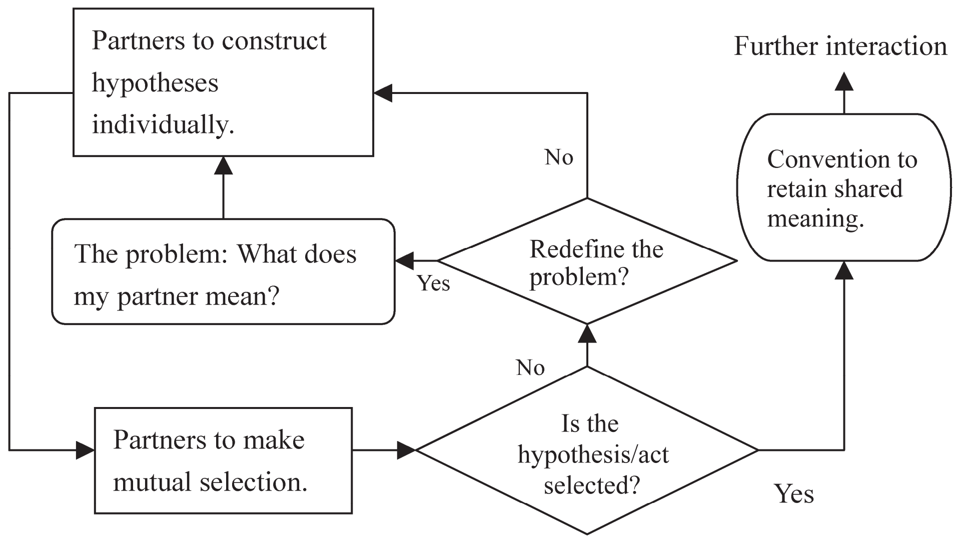

Figure 11. The evolutionary communicational process analyzed from the view of symmetric interaction.

every hypothesis in this process is assumed by its constructor to be successful until misunderstanding becomes manifest. When correction of meaning is made by one of the partner or when inconsistency of meaning occurs within the informational context, misunderstanding becomes explicit and the false hypothesis is to be selected out of the convention. It can be evident that, once three partners are involved, a model of triple EPSP is needed. The number of EPSP grows up when the number of participants in communication increases.

Even with no language exchange involved, imitation is still a kind of social communication process and can be well understood from the EPSP model. Although some traditional viewpoints may regard imitation as a mechanistic behavioral mimic, the EPSP model considers it as an active constructional process. Starting with the intention to imitate, the imitator has to imagine the imitated actor's internal states (including psychological and/or physiological states), to construct a hypothetical way of action in his/her own mind, to try out the possible way of action, to compare the action itself as well as the effects of the action to those of the actor to be imitated, and to make an evaluation of the imitative action. If the evaluation is satisfying, then the way of action is preserved. If the evaluation is not satisfying, then the way of action is eliminated and a new cycle of EPSP can be restarted. Moving away from errors, the new cycle of EPSP is an intended correction of the old cycle, although the new solution is not determined to be better. Combining different cycles of EPSP forms the self-regulating process, which is a chaotic random walk within a gradually diminishing boundary constrained by a strange attractor.

EPSP on the Social-Cultural Level

When systems A, B, C, D in Figure 1 are respectively replaced by problems, persons, social systems and culture, we get a model of the evolutionary process on the social/cultural level, as shown in Figure 12. The basic idea behind this model has been

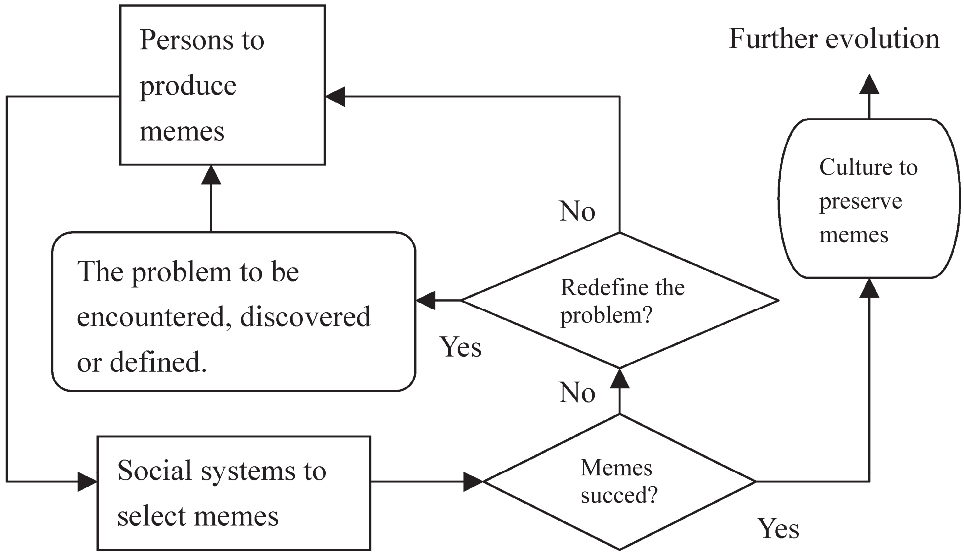

Figure 12. Cultural evolution as a problem-solving process.

proposed by Csikszentmihalyi (1988, 1999) as a background to his systems view of creativity. In this model, we still start with problems to be encountered, discovered defined/redefined or interpreted. Persons produce memes, which could be units of ideas, concepts, strategies or theories, to try to solve the problems. If the trial fails, persons go back to re-interpret the problem situation or to propose alternative memes and a new iteration restart. Innovation, art creating and scientific inquiry can all be viewed as EPSP on the social/cultural level.

Innovation and creativity as an EPSP

Based on systems approach, Csikszentmihalyi (1988, 1999) proposed a more appropriate question of "where is the creativity" to replace the traditional question of "what is the creativity." In his view, creativity lies on the interaction among the person, the field, and the domain rather than lies within the persons. With biological talent and personal experience, persons produce variation of ideas and works. However, those products cannot be creative by themselves unless that they are judged by a field. Related with a domain, a field is a community composed of the gatekeepers within a social system. Some of the examples of gate-keepers include: foundations which support academic research, museums which select work of art, journal editors and peer reviewers who evaluate research papers, audience and consumers who might buy the products, etc. When products are successfully selected, they will be preserved in a domain, which is a symbolic system composed of inter-related items of information, laws, theories, working steps, action strategies, etc. Only those products of being successfully selected by a field can get into a domain, become part of human culture and be transferred to the next generation by education. Without opportunity to be selected by a field, any novel product cannot be creative on the social/cultural level. Csikszentmihalyi's view of creativity is reconstructed with the current model of EPSP, as shown in Figure 13.

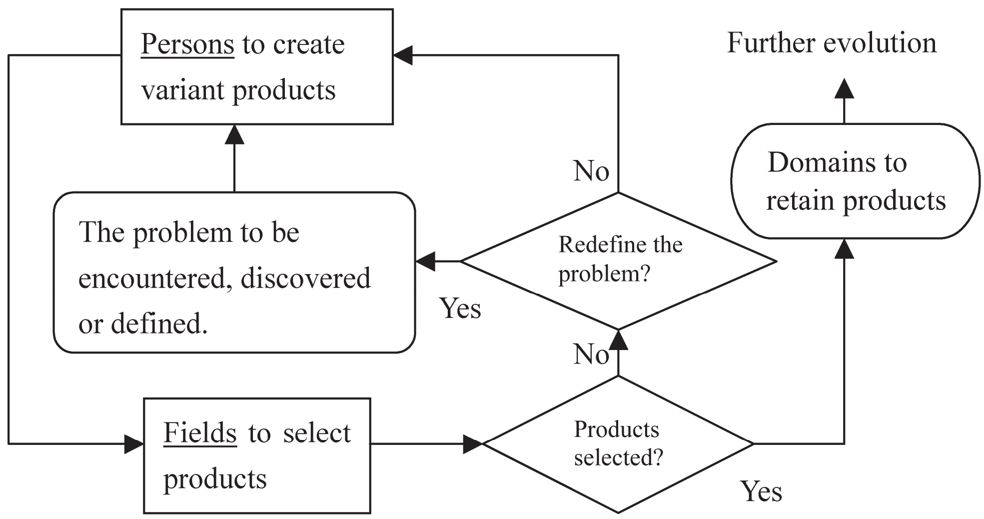

Figure 13. Csikszentmihalyi's (1988, 1999) model reconstructed from an evolutionary perspective.

Scientific inquiry as an EPSP

The traditional view about knowledge, knowing, and the basic nature of scientific inquiry is based on empiricism and promoted by logical positivism. This view claims that: 1) We human beings have a direct way of knowing the environment; 2) Human perception copies the structure of the environment; 3) Facts, coming from human immediate perception, can be utilized to positively confirm theories and even to gradually form scientific knowledge (Suppe, 1977). In the core of positivism is inductivism, which maintains that human beings receive information from outside, that observation is prior to hypotheses, and that scientific progress is due to piecemeal accumulation of facts.

The traditional view was severely challenged in the field of philosophy of science. Karl Popper is probably the first powerful challenger. He alternatively proposed his falsificationism, arguing that the basic nature of scientific inquiry is a bold-conjecture-and-free-criticisms process (Popper, 1959, 1963, 1972). He explicitly stated that:

> "…the growth of our knowledge is the result of a process closely resembling what Darwin called 'natural selection': that is, the natural selection of hypotheses: our knowledge consists, at every moment, of those hypotheses which have shown their (comparative) fitness by surviving so far in their struggle for existence (Popper, 1972: 261)."

Popper (1974) believed that scientific inquiry begins with problems and that hypotheses are psychologically prior to observation. He argued for critical realism and the necessity of the existence of a real world, the physical world ("world 1"). The individual mind, which decodes information, proposes hypotheses and construct theories but does not have any 'given' or 'direct' knowledge about the physical world, is called 'world 2' by Popper. However, the distinctive feature of science, Popper thought, is that science is composed of inter-related problems, theories, and errors formulated in a descriptive and argumentative language, which constitutes "world 3." The existence of "world 3" demonstrates the continuity as well as the discontinuity between human and animal knowledge. Because of being descriptive and argumentative, world 3 can be objective. Popper's view of science opened a way to evolutionary epistemology and is reconstructed in Figure 14.

After Popper's challenge to positivism, Kuhn (1970) opened the post-positivism age. Disagreeing with Popper, Kuhn found that scientists do not give up their paradigms after a few refutations. Paradigms are so enduring and persistent that they will not be replaced until they go through severe crisis and face a promising competitor. On the other hand, Popper and some other philosophers criticized Kuhn with the following points that: a) The meaning of "paradigms" is too vague; b) The argument of incommensurability between different paradigms paves the way to epistemological relativism; c) The dominant role of a paradigm in normal science gives no opportunity for criticisms and, therefore, no room for rationality.

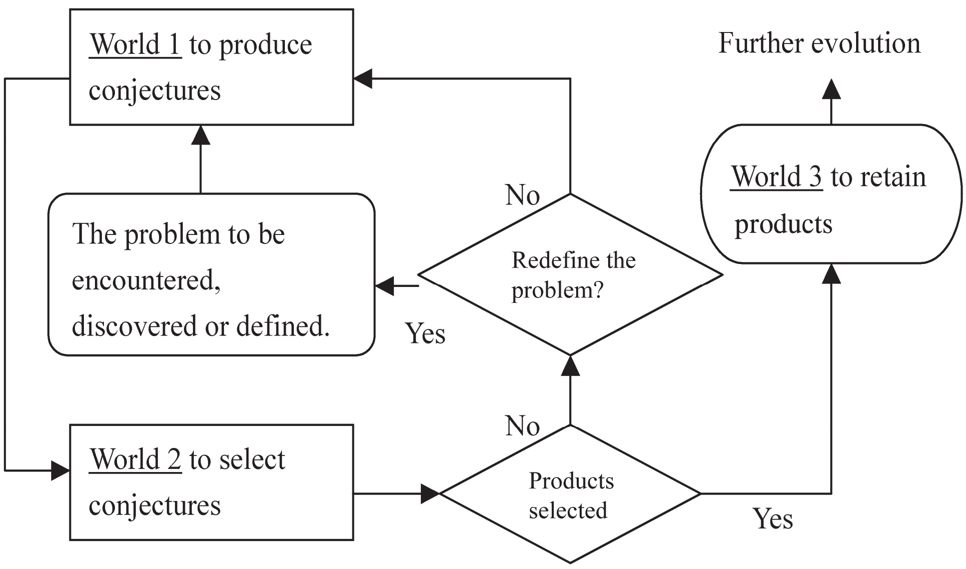

Figure 14. Popper's view of science reconstructed from an evolutionary perspective.

Despite the above disagreements and criticisms, Kuhn's view of scientific inquiry also reveals a strong sense of evolutionary perspective. According to Kuhn (1970), an individual scientist is strongly constrained and facilitated by his/her paradigms but actively interprets his/her problems and deductively proposes his/her tentative solutions for "puzzle-solving," especially during the period of normal science. The scientific community determines the adequacy of tentative solutions and shapes the form of paradigms. Since this community is composed of individual scientists who are strongly constrained by the dominant paradigm, the community is therefore strongly affected by the dominant paradigm too. Interpreted in this way, Kuhn's view of scientific inquiry can be reconstructed from an evolutionary perspective in the model as shown in Figure 15.

In order to illustrate creativity in science, Clement (1989) proposed a model of " model construction," which is an elaboration of Popper's view. In the core of Clement's model is an iterative hypothesis-testing process, in which the following viewpoints were

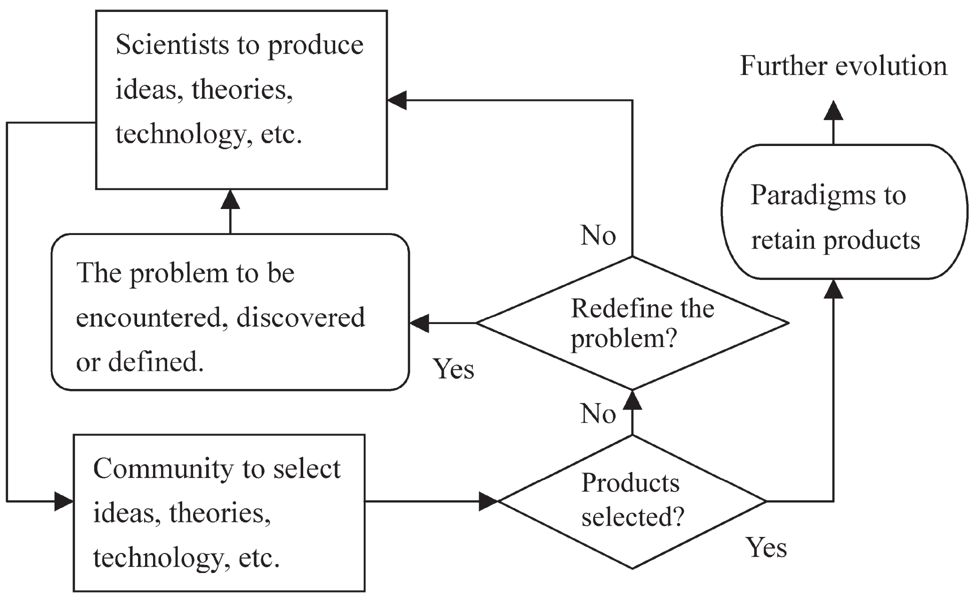

Figure 15. Kuhn's view of science reconstructed from an evolutionary perspective.

emphasized: a) Initial observation, analogical thinking, and elements in related models can be used to form hypotheses or construct initial models; b) Theoretical assessment of the initial model for logical consistency is prior to empirical assessment; c) Successful initial models are preserved for further assessment, while failed initial models are rejected or modified. Clement's (1989) model also reveals a strong sense of evolutionary process.

It should be pointed out here that the selection criteria used by both "world 2" (in Figure 14) and "community" (in Figure 15) include either empirical evidence or theoretical adequacy or both. Therefore, not only experimental but also theoretical scientists are engaged in evolutionary problem-process. In addition, scientists use not only real experiments but also thought experiments to evaluate the appropriateness of the ideas created by themselves or by their peers (Gardner, 1993). In a thought experiment, a problem situation is derived from some assumptions and then possible consequences are inferred. When inconsistent or unreasonable consequences are obtained, the original assumptions are questioned and modified. This is a kind of EPSP frequently adopted by theoretical scientists, mathematicians, philosophers, and etc.

Art creating as an EPSP

Csikszentmihalyi's (1988, 1999) model reconstructed in Figure 13 is applicable to scientific inquiry as well as arts experience. The problem for an artist is to create some products which are both new and valuable. Products, including music, fine arts, and performance arts are subject to selection by fields composed of critics, collectors, buyers, audience, museum officers, peer artists, etc. Selected products are to be preserved in their domains and become part of local culture or human culture. As a result, existent domains and culture are evolving and will have new effects on the artists (including the original artists) who are going to make new products.

The cognitive process of the individual artist is a vicarious one of the above social/cultural process. A successful artist needs not only technical skills but also knowledge of criteria for evaluating products. Criteria come from historical development of domains and from some value systems within the culture. When an artist does not agree with those criteria, he/she may develop new criteria or even form a new school. However, he/she cannot simply ignore criteria. Otherwise, his/her probability of being a successful artist is near zero.

General people might think that individual artist create products according to finished vicarious products in his/her mind. This is not the case, however, according to Gardner's (1993)research about Picasso. The creating process of Picasso is full of trial-and-error and hypothesis-testing action. For example, from the sketch of the work "La vie," we can find that Picasso tried different roles, postures, and emotional expressions of the characters in the painting. In order to form new configuration, he rearranged the relationships between the characters in the painting as well as recombined the elements in his previous works. For creating another work "Les Demoiselles d'Avignon," the beginning representative work of cubism, Picasso left at least eight volumes of private notebooks about the sketch of this excellent work. From his notebooks, we can find that many characters (such as a sailor) and objects (such as a book and a head skeleton) that had appeared in earlier sketch disappeared from later sketch. The number and emotional expression of the characters in his later sketch also changed for many times. For creating the work "Guernica," probably the most outstanding work of Picasso, he left at least forty-five sketched works, six of which tried to form a whole configuration and the others were involved with the experimentation of individual expressions of human beings and animals. Through those trials and experimentation on background, position, relationship, emotional expression, and symbolic meaning, Picasso kept some patterns constant while changed other patterns from time to time. It seems that the process of trial-and-error for Picasso is a combination of heuristic tries and blind tries. This is also a typical EPSP filled with creative thinking, critical thinking, and feedback information.

Typology of Variation

The concept of "variation" in the EPSP model presented above includes "blind variation" and "variation based on prior evolution". Blind variation does not require equiprobability or statistical independence among variations (Campbell, 1960). It need not be random, unsystematic, or unconstrained (Cziko, 1998). It only requires that no prior knowledge can be used to produce the variation that is worthy to be selected, so that the variation is independent of the selection conditions. In other words, "a blind variation is essentially a trial whose outcome is unknown when first proposed or generated (Cziko, 1998: 194)." When a variation is successfully selected and retained, it can be reproduced.

Variation based on prior evolution, can be differentiated further into at least three kinds of variation: reproduced variation, heuristic variation, and sighted variation. Heuristic variation is based on implicit knowledge while sighted variation is based on explicit knowledge, so that both are knowledge-based variation. Reproduced variation is an imperfect replication of prior successful variation that is retained. On the biological level, a combination of blind variation and reproduced variation is necessary for improving the adaptation of a species. On the cognitive and cultural level, a combination of blind variation and knowledge-based variation is necessary for solving a problem.

Many researchers are unwilling to accept evolutionary theory as a viable theory for illustrating the problem-solving process or creative thinking because it is so obvious that we human beings solve our problems with so many sighted, heuristic, and knowledge-based trials. For example, Sternberg (1998) agreed that evolution is powerful to produce adaptive organisms and that biological evolution shows emergent properties. However, he disagreed that the blind-variation-and-selective-retention theory is appropriate to model human creativity. His reasons included the follows. First, this theory is not empirically well supported. Second, studies of experts vs. novices and of artificial intelligence revealed the role of sighted variation. Third, blind variation is inefficient to produce creative ideas for problem solving. Fourth, this theory is unable to explain the creativity of outstanding individuals such as Shakespeare. He argued that, in human creativity, we need a rapid form of evolution. He then proposed a sighted-variation approach to human creativity, explaining human creativity according to his triarchic theory of human intelligence.

Indeed, human beings solve many problems with sighted variation, which comes from learning and development on the individual level, and with heuristic variation, which is based on biological wisdom accumulated from long history of evolution on the genetic level. Both sighted and heuristic variation comes from the retention mechanism, which preserves the variation that is emitted at the very beginning as a blind variation but successfully selected. When a totally novel problem situation is encountered and all prior knowledge (including biological wisdom) cannot help to solve it, blind variation is indispensable. Just as Campbell (1960) pointed out, a blind-variation-and-selective-retention (BVSR) process is fundamental to all inductive achievements, including all genuine increases in knowledge. Even additional processes shortcutting a full BVSR process are in themselves inductive achievements, containing wisdom achieved originally by this full process. Such shortcut processes contain in their own operation a BVSR process at some level, substituting for overt loco motor exploration. With Cziko's (1998) typology of BVSR as a prototype, the current paper depicts the complementary relationship between blind variation and variation based on prior evolution for different types of behaviors and of genetic dynamics, as shown in Figure 16.

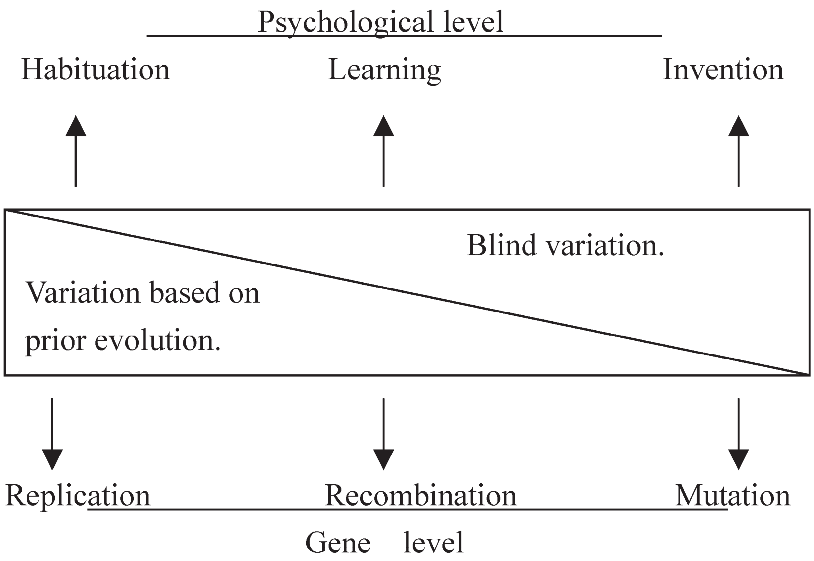

Figure 16. Complementarity of blind variation and variation based on prior evolution.

Conclusion

The core epistemological position implied by the above EPSP model is the variation and selection constructivism (Bickhard, 1992a). This position is basically consistent with Campbell's (1960, 1974) evolutionary epistemology, Cziko's (1998) selectionist theory, Rescher's (2000) process philosophy, von Glasersfeld's (1995) radical constructivism, and Wuketits' (1984) evolutionary epistemology. A list of interrelated themes incorporated by the current position is given in the following.

1. Creative thinking is required in problem-solving processes when habitual hypotheses fail. All genuine creativity comes from blind variation and selective

retention.

2. Most problem-solving processes need a combination of blind variation and variation based on prior evolution.
3. Perception is the knowing agent's active construction of the pattern of the external world. Before a successful hypothesis is constructed and accepted, the external objects, events, and actions in the environment are encountered but are non-perceived and non-meaningful to the knowing agent.
4. Perception is imperfect, adaptive, and biologically relative because it is based on organs, which are evolutionary products.

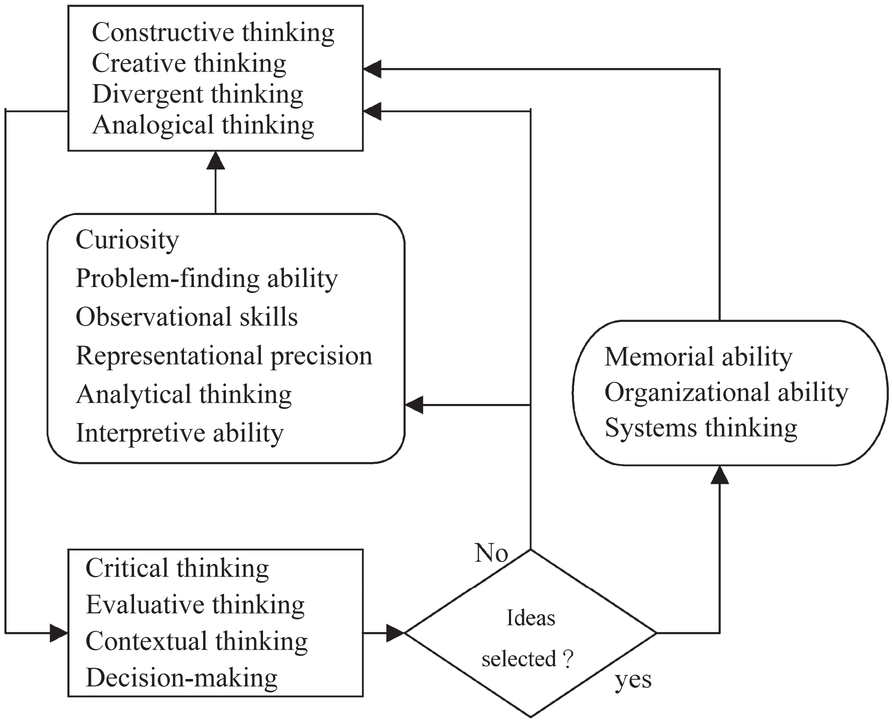

Figure 17. Some abilities, thinking skills, and dispositions suggested by the EPSP model.

5. Reading comprehension is a constructive hypothesis-testing process rather than an information-receiving process.
6. Communication is an information-transformation process rather than an information-transference process. All participants in a communicational situation are engaged in constructive hypothesis-testing process.
7. We human beings, as kind of knowing agents, only have an indirect way of knowing our environments. Our knowing process is a Darwinian cognitive process.
8. All knowledge is the result of direct or indirect evolutionary process.
9. All knowledge is viable rather than ontologically true.
10. Knowledge out of the EPSP is objective if it is selected by system C (in Figure 1), which is external to rather than a subsystem of the knowing agent.
11. Knowing agents, especially human beings, construct fallible internal indicators of external selection pressures. Therefore, the EPSP in their cognition is a vicarious process of the EPSP on the social/cultural level.
12. On the vicarious psychological level, some abilities, thinking skills and dispositions shown in Figure 17 according to the EPSP model may be important for a learner to become a successful problem solver. They are domain-specific, though the form of their interrelationships is domain-general. In educational practice, to nurture the abilities and dispositions listed in Figure 17 can be advantageous for a learner to become a good problem finder and an efficient problem solver.

Discussion

As pointed out by Bickhard (1995), among many versions of constructivism, variation and selection constructivism is the version that has the possibility to escape the classic epistemological traps proposed by skepticism to empiricism and rationalism.

The current paper exemplified this theory and intended to show the generalizability of it. Since generality is emphasized, specificity is sacrificed. Many important aspects of the theory still need to be explicated in the future.

First of all, the conceptual relationships among the four systems (in Figure 1) on different levels should be delineated. These will involve the definition, the components, the boundaries, the properties and the categories of each system as well as the logical relationships among the four systems. For example, the goal in system A (the problem) should be internal to the system B (such as an agent), while the constraints in system A constitute parts of the selection pressures in system C. In addition, on the cognitive level, system C can be indicated in system D (such as a belief system) and become a vicarious system within system B.

Secondly, there are different kinds of problems (such as ill-structured and well-structured problems) and different domains of problems (such as mathematical, biological and ethical problems). How to apply the EPSP model to analyze those different kinds and domains of problems is a problem deserving further exploration. In particular, the model should be able to show the possibility of getting out of local solution and to show the commonality and specificity among different domains.

Thirdly, the interactive relationships among the four systems on each level should be refined. For example, how is system A (the problem) represented by system B (the knowing agent)? How is system C (selection pressures) perceived (or "internalized") by system B and retained in system D? How does system D affect system B and therefore constrain the latter's interpretation of problems and production of variations? How is system B able to loosen, to replace, or to reorganize constraints from system D (such as a paradigm). To solve those problems will result in sub EPSP models within an EPSP model, reflecting the model's self-similarity at different levels as the chaos theory showed.

The relationships between variation and selection are especially intriguing. While blind variation is independent of selection, variation based on prior evolution is not. Especially on the cognitive level, a high proportion of hypotheses produced by the knowing agent are guided by the selection criteria but are also able to direct the observation and evaluation performed by the selection system. Here, a treatise of "good thinking" and of "theory-laden observation" can be called on. Besides, it will be impossible to talk about "stability," "objectivity" and "rationality" when variation is promoted without selection. However, any selection pressure can be harmful to the amount of variation especially when it is strong, dominant and exclusive. Therefore, a discussion of authoritative selection pressure in political, educational and cultural contexts from the evolutionary perspective can be valuable. Furthermore, at the human individual level, some selection pressures are harmful to the intrinsic motivation of the creator (Collins & Amabile, 1999). It is also clear that overwhelming selection pressures can paralyze a learner, so that an analysis of muting and blocking the selection pressures for the learner, i.e., of scaffolding and self-scaffolding, are necessary (Bickhard, 1992b).

Fourthly, the typology of selection pressures and its relationships with decision-making should be investigated, distinctively on the psychological and social level. Toulmin (1972) differentiated "causes" from "reasons," both of which participate in selection of scientific theories. Shapere (1984) differentiated "relevant information" from " irrelevant information," both of which also involve the selection of scientific ideas. There are still other categories of selection pressures such as "internal reasons" vs. "external reasons." Such kinds of contrasts are used to differentiate rational decision-making from irrational or non-rational decision-making. Here, a model of rationality is essential (Bickhard, 1991).

Finally, the role of probability should be made explicit and expressed in the model with a more visible strategy. Probability is intertwined with the variation and selection process, maintains open-endedness in evolution, and gives the possibility of free choice for all evolutionary open systems.

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