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Knowledge, Self-Regulation, and the Brain–Mind Cycle of Reflection

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The structure of everyday language implies that knowledge is an object. Like an object, it can be acquired, lost, stored, retrieved, and used. Anything that might be done to an external object could also be done to knowledge. Using concepts from the emerging field of biofunctional cognition, this paper discusses an alternative to the everyday-language framework of knowledge. The central idea is that the biological subsystems that comprise the physical nervous system have the capacity to create in us a live, as opposed to pre-recorded, experience that might be described as intuitive self-awareness. In its various manifestations, this ongoing intuitive self-awareness is what we recognize as the knowledge inside us. There is no storage of knowledge of any kind. Intuitive self-awareness is in a perpetual state of re-creation and change. It serves as a private language with which the individual interacts *directly* (or nonsymbolically) with the subsystems of his/her own nervous system. This is the primary function of intuitive self-awareness — serving as the vehicle for the private communication between the individual and the individual's nervous system. Intuitive self-awareness has also come to serve, through evolutionary symbolic adaptation, as the foundation for the public language that the individual uses to communicate with other individuals. This is the secondary function of the intuitive self-awareness — to serve as the vehicle for public communication within social groups in which the individual lives. In this function, intuitive self-awareness externalizes to manifest itself in the form of an *indirect* (or symbolic) code system for public communication. The nonsymbolic and symbolic forms of knowledge enable the organism to extend its internal world to encompass the external world in both its totality and detail.

Everyday language is packed with suggestions that knowledge is an object-like entity. Evidence for this comes from the abundance of what Reddy (1979) called conduit metaphors of daily communication. Conduit metaphors

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are verbal (or symbolic) frames for holding and transporting knowledge in daily communication. Examples include: *The author's important ideas are lost in the multitude of trivial detail, Find the main idea of this paragraph, It's hard work to put ideas down on paper,* and *Who gave you that idea.* The abundance of conduit metaphors suggests that people's external and internal worlds are both populated with knowledge forms called ideas, concepts, meanings, or the like. These knowledge-objects are simultaneously within and outside the reach of the human intellect, existing in a nebulous twilight zone that motivated the behavioral philosopher Ryle (1949) to refer to ideas as ghosts in the machine.

This mental twilight zone, which was pronounced by behaviorists to be the arid territory for scientific research in the first half of the twentieth century, became fertile ground for cognitive research in the second half of the century. The cognitive science laboratory has itself produced a new generation of conduit metaphors such as information processing, the long-term memory store, memory search strategies, networks of knowledge, and making connections. These metaphors were used to address a new generation of questions in cognitive science about the object states of knowledge: How is knowledge organized in long-term memory? What are the capacity limitations of the information processing stores? What strategic resources differentiate good and poor information processors?

The origin of conduit metaphors is as old as the origin of the concept of knowledge itself. *Mnemosyne*, the goddess of memory, roamed both the everyday and the intellectual worlds of the ancient Greece. However, her influence was not to remain confined within the Hellenic borders. The abundance of conduit metaphors of daily communication made it easy for her ghost to invade osmotically the deepest crevices of the human intellect around the globe. There she secured a permanent home, camouflaged by ever-renewing layers of Plato's doctrine of recollections or Aristotle's logical positivism (see Broudy, 1977; Gulley, 1961; Maguire, 1973; Mann, 1980; Reynolds, Sinatra, and Jetton, 1996; Shulman and Quinlan, 1996; Swartz, 1998; White, 1976). This camouflage turned out to be so perfect, and the osmotic seduction of conduit metaphors so ubiquitous, that it took more than two thousand years of intellectual struggle, and the realities of the computer-inspired cognitive revolution, to begin to unveil the ghost of *Mnemosyne* out of her mysterious stronghold and to cast serious doubt on the value of the conduit metaphors of human knowledge.

Conduit metaphors of knowledge are not the only relevant metaphors available in the language of daily communication. Reddy (1979) identified another less prevalent set of metaphors that might be characterized as constructive metaphors of learning. Examples of these are: *I know what you mean, I think I understand what you have in mind, I have my own interpretation* *of this statement, I hear what you are saying, I think I see what you are doing and I like it,* and *I believe I can figure things out by myself.* The problem with this set of metaphors is that they seem to signify the end result, or product, of some complex set of internal processes that have so far remained a mystery to human understanding. Consider, for example, the constructive learning metaphors *I know* or *I understand.* They each signify the end result of some unpacked internal process. It is meaningful to say "I know" or "I understand," especially if the object is understood. However, it is not so meaningful to say, "I know how to know" or "I know how to understand" (Iran-Nejad, 1978). The reason we cannot make the latter statements is that we know nothing about the underlying process by which we come to know or understand something. We might say that our understanding of constructive learning metaphors still suffers from Harnad's (1990) symbol grounding problem (see below) because these metaphors signify a process whose nature is still outside the reach of our understanding.

We know enough about constructive learning metaphors to recognize that they suggest a perspective on human cognition that is dramatically different from the perspective implied by conduit metaphors of knowledge. Unfortunately, this is all we know. Beyond this vague suggestion, our understanding of the constructive learning metaphors craves for a solution to the symbol-grounding problem. Otherwise, constructive learning metaphors are likely to either remain in a buzzword state or revert to the status of conduit metaphors of knowledge. For example, the information processing theory has been cast as a theory of "memory" (Atkinson and Shiffrin, 1968). Can it also be considered a theory of "understanding"? The answer to this question is affirmative to the extent that conduit metaphors of knowledge can be used to refer, in part or whole, to an underlying process whose end result is understanding. In fact, later extensions of Atkinson and Shiffrin's original information processing theory talk about shallow and deep processing of knowledge (Craik and Lockhart, 1972). However, the fact that the formulation of the symbol-grounding problem postdates the depth of processing approach is a clear indication of the ineptness of the conduit metaphors.

There is nothing inherently wrong with the metaphors deep or shallow. In fact, the metaphors themselves stress the need for a solution to the symbol-grounding problem. Where we go next depends on what we make of deep processing. If we go back to defining this process as making connections beyond those explicitly suggested by the input symbols, we are likely to see the process underlying constructive learning metaphors like "understanding" as internalization of external symbols by means of elaborative rehearsal. We might end up again embracing the conduit-metaphor solution as the only solution to the symbol-grounding problem, admitting that constructive learning is the end result of the linear process of making connections. Therefore, as a possible underlying process, elaborative rehearsal has the potential for removing the advantages of constructive learning metaphors over conduit metaphors of knowledge-as-an-object by reducing the former to the latter altogether. Our search for an alternative solution has the potential to result in a boomerang effect.

Grounding constructive learning metaphors in conduit metaphors of knowledge may be an important endeavor in its own right. However, equally important is to recognize that the two sets of metaphors suggest dramatically different perspectives, a situation that challenges us to consider the road not taken. In information processing theory, constructive elaboration essentially amounts to grounding input symbols in more of the same — via such process metaphors as connecting units, searching networks, or ascending/descending hierarchies. But constructive learning metaphors such as understanding suggest experiences of a fundamentally different kind. For one thing, we have been reminded often enough that understanding, for example, is more than the sum of the elements involved in the interconnections that result from the constructive elaboration process. This is probably why the statements *I know how to elaborate* and *I know how to understand* have different effects on people's intuitive judgements of meaningfulness. Elaboration does not point to something beyond the bounds of what we feel we know how to do. By contrast, understanding does, implying to that extent that we do not know how to understand.

Constructive elaboration refers to a process within the realm of conscious control. We know *in our mind* how to do it; we know what process to follow. Understanding occurs outside the realm of conscious control. We do not know what process to follow because the underlying process, having always occurred outside the realm of our conscious mind, is still a mystery to us. To be sure, constructive elaboration might be said to facilitate understanding. However, adding more links does not ensure the extraordinary click of understanding. Something else must! Therefore, grounding constructive learning metaphors in conduit metaphors of knowledge would amount to disregarding this potentially significant difference.

Another problem with grounding constructive learning metaphors in constructive elaboration is that such a practice is likely to gain linear momentum toward (ungrounded) overabstraction, overelaboration, or overparticularization of symbols (Iran-Nejad and Ortony, 1984). A classic case of overabstraction is implied by the concept of higher order thinking. It might be assumed that the highest-order kind of thinking is the best kind of thinking. However, when this vertical dimension is seen in terms of the degree of abstractness, it runs the risk of overabstraction to the extent that it reduces natural (multidimensional) thinking to the single dimension of abstractness per se. Thus, as thinking climbs the narrow vertical ladder of abstraction, it becomes less and less grounded because it leaves behind the many dimensions that serve, in combination, as the natural ground for it. Overelaboration and overparticularization may be illustrated similarly. Harnad (1990) used what he called "the Chinese/Chinese dictionary-go-round" to illustrate the severity of the symbol grounding problem. He stated, for someone with no expertise in Chinese, "the [linear] trip through the dictionary would amount to a merry-go-round, passing endlessly from one meaningless symbol or symbol-string (the definiens) to another (the definiendum), never coming to a halt on what anything meant" (p. 339). Trying to ground constructive learning metaphors such as "understanding" in conduit metaphors of knowledge amounts to forcing one's way through a Chinese/Chinese dictionary-go-round of constructive learning buzzwords.

Grounding Constructive Learning Metaphors Directly in Brain Functioning

Knowing how "understanding something" takes place is likely to require expertise in how the brain functions to bring about understanding. The same is the case with hearing something, seeing something, and other mental functions. We know how to listen to an object or look at one; but we do not know how to see or hear an object. We just know that seeing or hearing happens to us — that's all. Only the brain knows how to understand, hear, or see. This means that the brain has ways of doing things that are still unknown to us. The brain's kind of know-how requires expertise in how the subsystems of the nervous system like audition and vision work. This reasoning suggests that grounding constructive learning processes might be based directly on insights about how the nervous system functions. Elaborating, listening, or looking do not ordinarily require such special expertise. From the viewpoint of communication, brain "know-how" expertise constitutes a different field with its own set of tacit perspectives and language — different from the perspectives and language of everyday communication. Elaborating, listening, and looking are well within the realm of everyday language.

Therefore, there are at least two very different realms of exploration for grounding constructive learning metaphors: in conduit metaphors of knowledge and in the functioning of the brain. In retrospect, in identifying and denouncing the mental twilight zone of conduit metaphors as a ghostly place, behaviorists may not have been as mindless as the mid-twentieth century cognitive revolution made them appear. Historically, many scholars of cognitive science have also objected to grounding constructive learning metaphors in conduit metaphors of knowledge (Bartlett, 1932; Bransford, McCarrell, Nitsch, and Franks, 1977; Iran-Nejad, 1980; Jenkins, 1974; John, 1972). However, in the absence of a sufficiently developed alternative approach, many researchers continue to believe that conduit metaphors of knowledge provide a useful way of thinking about human cognition. At the same time, criticisms of these metaphors are reaching epidemic proportions (Clancey, 1997; Iran-Nejad and Ortony, 1984; Mayer, 1992; Wittrock, 1992). Moreover, detailed theories of how the nervous system functions have begun to make their appearance in the literature (see Iran-Nejad, Wittrock, and Hidi, 1992). Many of these theories have explicitly disavowed the conduit metaphors of knowledge and attempted to ground constructive learning metaphors directly in brain functioning.

A useful place to start thinking about grounding constructive learning concepts in brain functioning is to reflect on the parallel area of reconstructive surgery. When a lesion occurs in body tissue, we know how to wrap or sew the wound. We may even manage to introduce new tissue from some other part of the body. Roughly speaking, this is analogous to constructive elaboration. However, sewing a wound is not the same as healing the wound, something we do not know how to do. In the realm of everyday communication, healing — as in faith healing — would be synonymous with performing a miracle. Faith healing is as surprising as it is because it is beyond the "know-how" of ordinary people. Only our bodies know how to heal by means of what is currently a mysterious constructive process. The same is true of constructive leaning processes. To claim "I know how to understand" is intuitively unacceptable for the same kind of reason that "I know how to heal" is recognized as a miracle. The body knows how to heal wounds and the brain knows how to understand something. Therefore, mental know-how and brain know-how may be viewed as different as the "know-how" required for practicing reconstructive surgery and the body's know-how for healing.

The Brain as a Figure–Ground Navigation System

If the brain is not a storage–retrieval system, then what kind of a system is it? Of course, assuming that the brain functions in the manner suggested by the conduit metaphors of everyday knowledge is an important perspective in its own right. In fact, as the computer metaphor suggests, the brain may indeed turn out to be an information (or object) processing system (see Iran-Nejad and Ortony, 1984). We must, however, consider alternative perspectives that can speak more directly to the intimate relationship that is likely to exist between proximal, "how the system works" kinds of influences, and the distal roots of these influences in evolution (Scarr, 1992, 1993). Accordingly, biofunctional cognition maintains that the nervous system is, by evolutionary design, not a storage–retrieval but a figure–ground navigation system (Iran-Nejad, Marsh, and Clements, 1992; Iran-Nejad and Venugopalan, 1998).

First, "organisms are what they are today because the nervous system (not the mind) solved fundamental survival problems as it evolved, just as the immune system solved fundamental survival problems as it evolved. Second, the brain's evolution-tested biofunctional processes evolved as survival solutions to figure–ground (FG) problems, which were originally more basic and important to survival than storage–retrieval processes" (Iran-Nejad, Marsh, and Clements, 1992, p. 474).

The figure–ground hypothesis, as proposed by Gestalt psychologists, means that external objects are perceived when they become segregated as figures from the external ground in which they are naturally embedded. In effect, this process operates in accordance to perception's constructive laws of organization. Biofunctional cognition extends the figure–ground hypothesis to propose that the brain's constructive learning processes have all evolved to work as figure–ground navigation processes. The idea is that the brain has evolved to build and sustain, on an ongoing basis, an internal ground — not just for navigating our way around in the physical world but for all aspects of mental functioning. Psychologically, this internal ground manifests itself from one moment to the next as an ongoing self-awareness of what we know. Everything we know is tacit in this ever-evolving internal ground in the sense that the brain does not need to preserve segregated knowledge objects permanently. Rather, it can create them by segregating them live from the ongoing "intuitive knowledge base," or internal ground within us, according to its laws of figure–ground segregation and the demands of the moment (Iran-Nejad, 1989).

The brain's figure–ground system may be described from many different viewpoints. From the viewpoint of brain functioning, biofunctional cognition maintains that the nervous system engages in two qualitatively different kinds of activity. One is ongoing brain activity (OBA) of all brain subsystems together. This type of activity represents the constructive learning process responsible for creating and upholding the brain's ever-evolving internal ground. The second is momentary constellation firing (MCF) in which a distributed constellation of brain microsystems engages in a sudden burst of synchronous firing. This type of activity represents the constructive learning process responsible for segregating individual figures from the brain's ongoing internal ground (Iran-Nejad, Marsh, and Clements, 1992).

Knowledgewise, OBA (the ground) and MCF (the figures) are represented by two qualitatively different kinds of intuitive self-awareness (or knowledge). One is thematic knowledge (TK), which is responsible for the stable totality of one's ongoing experience. As far as the relationship to the real world is concerned, TK is pre-representational in that it has not been reorganized yet into domain-specific concepts representing various aspects of the world. The other kind of knowledge is categorical knowledge (CK), which represents the ever-changing sequence of temporary figures. The pre-representational TK serves, in a sustained fashion, as the internal context for representational CK, or the sequence of relevant concepts, propositions, and perspectives. Two kinds of TK may be distinguished (Iran-Nejad, 1994): themes and wholethemes. Wholethemes are domain-comprehensive, all-encompassing, and pre-representational. An example is the wholetheme of space. The intuitive awareness of space as we experience it within ourselves is comprehensive of all domains of intuitive self-awareness. Our intuitive self-awareness of such wholethemes as space, time, and freedom — with their depth, vastness, permanence, all-inclusiveness, and so on — cannot be reduced to a single dimension of abstractness. What the brain accomplishes in creating such wholethemes is miraculous in the true sense of the term. Themes are neither domain-comprehensive nor domain-specific. Rather, they lie at the dawn of domain-specificity and serve as the immediate grounds for domain-specific concepts. As such, they exist at the threshold of the representational world. Wholethemes (e.g., intuitive self-awareness of space or time) are prolific of themes (e.g., intuitive self-awareness of settings and eras). As it relates to brain functioning, a wholetheme is a dynamic organization; but a theme tends to enter the relatively static world of finished products. The click of comprehension mentioned earlier occurs when a theme emerges, perhaps in the form of an insight (e.g., as a freedom-loving individual hears for the first time the phrase "the governance of people by people), from the ground of a wholetheme (e.g., freedom) or a concept (e.g., our self-awareness of the verb "to release" or the noun "dictator") emerges from the ground of a theme (e.g., our self-awareness of a setting). Thus, as wholethemes are prolific of themes, so are themes prolific of concepts. Both themes and concepts are created by the brain by means of momentary constellation firing. Thus, wholethemes tend to be infinitely productive; but themes and concepts tend to be relatively less productive (see Iran-Nejad, Marsh, Ellis, Rountree, Casareno, Gregg, Schlichter, Larkin, and Colvert, 1995).

Thus, thematic knowledge is simultaneously domain-comprehensive and domain-specific. This twin role makes thematic knowledge an ideal vehicle for mediating the influence of prior experience on learning as well as for putting, and keeping, future goals in view (see Prawat, 1998), be they immediate or distant. A wholetheme begins when multiple internal and external sources come together in the form of an organic ecosystem to set the stage for the creation of a temporary perspective, follows its course while the learning sources stay in motion, and disappears when the learning sources no longer work together (see Iran-Nejad, 1989; Iran-Nejad and Cecil, 1992, for details). In this sense, a wholetheme is like the weather on an overcast day, when all the conditions necessary for rain are set in motion, at which time the rain begins and continues until the conditions in the atmosphere cease their work and the rain stops. The set of multiple sources that serve as the necessary and sufficient condition for rain and the set of multiple sources that uphold the wholetheme are analogous. The way the former set of multiple sources manifests itself in the form of a particular storm that is running its course is analogous to the more or less self-propelling theme of the wholetheme ecosystem. And, finally, the particularities that manifest themselves as wind, lightning, snow, and so on are analogous to categorical knowledge. No single source can perform in isolation what it can in the context of the entire ecosystem. And even though the wind of a sunny day and the wind of a rainy day may both be identifiable as wind, the two are never the same. Each instance of the wind is grounded in its own ecosystem.

Wholethemes are domain-comprehensive in yet another very important sense. Because a wholetheme represents the influence of multiple domain-comprehensive sources of brain functioning, its natural (self-propelling) tendency is to expand and permeate the entire realm of the brain's internal ground. Thus, the wholetheme of space places human imagination into an ever-expanding mode of functioning as does the wholetheme of time. In this sense, a wholetheme has momentum to push in either direction of two somewhat antithetical dispositional modes of (constructive or unconstructive) functioning. Constructive wholetheme modes of functioning govern curiosity, suspense, imagination, and interest. By contrast, unconstructive wholetheme modes of functioning tend to generate fear, stress, tension, and anxiety. Under normal brain conditions, both of these wholetheme modes of functioning can cause a great deal of incidental learning or learning not directly tied to the particular domain-specific knowledge being created by the ongoing wholetheme (Iran-Nejad and Cecil, 1992).

The representational figures that the brain creates in the context of the nonrepresentational wholetheme of the moment are also of two major kinds. *Direct* representations are those (a) whose relation to the nonrepresentational ground is direct or unmediated, (b) they are directly their own meaning, (c) they are nonsymbolic, and (d) they can be symbolic only metaphorically. Concepts such as dog, car, and gas station are direct representations. For instance, in today's world, the concept of gas station (a) has its own direct context, (b) serves as its own meaning (a gas station is a gas station), (c) is nonsymbolic (represents nothing else but a gas station), and (d) can be symbolic only metaphorically as in the statement *The house smells like a gas station*. By contrast, *indirect* representations are those (a) whose relationship with the nonrepresentational ground is arbitrary, (b) are dependent on direct representations for their meaning, and (c) are purely symbolic in that serving as a symbol for something else is their one and only function. For example, the English word for table and the French word for the same are different indirect representations. While direct representations stay more or less the same across different languages of the world, providing the foundation for translation, indirect representations are the stuff that cause languages to be different.

To illustrate how all of these might work together, consider the case of reading an engaging story. The words (or indirect representations) in the story play their propositional (and still indirect) role one after another. To engage the reader in the story plot, the story propositions must mobilize the person's intuitive knowledge base, thus establishing sustained (internal) grounding. This can occur, if and only if, the story causes a shift from propositional comprehension to what might be called dispositional comprehension. Propositional comprehension tends to remain shallow or ungrounded — it follows linearly, to use Harnad's (1990) analogy, the Chinese/Chinese (or English/English, Persian/Persian, etc.) dictionary-go-round of symbolic brain activity. If, on the other hand, the story propositions play their indirect role of mobilizing the brain's nonsymbolic sources (e.g., imagination, thematic knowledge, fear, curiosity, suspense), a shift is likely to dispositional comprehension. This dispositional mode of functioning remains ongoing by means of its self-propelling momentum until the story reaches thematic closure and the brain's intuitive knowledge base reaches wholetheme closure (Iran-Nejad, 1989).

For many individuals functioning within a supportive context, the ongoing wholetheme coincides with a more or less constructive mode of functioning that has momentum or flow (Csikszentmihalyi, 1988; Csikszentmihalyi and Csikszentmihalyi, 1988) toward encompassing the brain's intuitive knowledge base in its entirety, causing curiosity, suspense, and so forth on its constructive path. In this fashion, the wholetheme represents, functionally, an interest-creating discovery module (Iran-Nejad and Cecil, 1992). Thus, a well-formed story begins with a sequence of propositions, gradually unfolds into an interest-creating discovery module, and eventually reaches closure as the story ends. However, it is not necessarily the ending of the physical story as an external object that ensures figure–ground closure. Closure is in the mind of the reader. Some readers may feel compelled to talk about a story they have read for days after reading it, even entertaining various perspectives on the setting. Even when the (domain) specific theme of a story comes into existence in its full particularity, the story may have not reached closure in the mind of the reader. The story reaches closure in the mind of the reader when its domain-specific and domain-comprehensive aspects both reach closure. Neither is the closure in the mind of the reader permanent. As new contexts emerge, so does the need for more domain-comprehensive and domain-specific integration. Thus, after reading a story, the reader may feel the urge to tell others about it for a long time (see the section on self-regulation below).

Thus, in biofunctional cognition, the figure–ground hypothesis extends beyond perception to encompass mental functioning in its totality. For example, research we have conducted with human subjects has shown that the constructive disposition facilitates, and the unconstructive disposition debilitates, identification of the figures embedded in magic eye pictures (Iran-Nejad and Venugopalan, 1998; Sheynfeld and Iran-Nejad, 1999). Undergraduate educational psychology students were each presented a packet containing instructions and a randomized set of magic eye pictures. Subjects also completed a checklist of the constructive/unconstructive emotions they experienced both before and after each picture. Immediately after finding the image hidden in a magic eye picture, each subject was to write down a concise description of the hidden image. The variables of main interest were the disposition-before, disposition-after, and number of correctly identified images. Pearson correlations showed highly significant positive correlations between the number of correctly identified images and the constructive disposition ($r = .63$ for before and $r = .71$ for after) and correspondingly high negative correlations ($r = -.62$ for before and $r = -.67$ for after) for the unconstructive disposition.

This manner of thinking about the relationship between cognition and brain functioning promises to integrate hitherto disjoint levels of analysis and fields of exploration. For instance, electrophysiological (e.g., event-related and other types of brain waveform), experiential (e.g., suspense, curiosity, insight), and behavioral (e.g., verbal reports, think aloud protocols, written essays) measures can be mutually grounded in various manifestations of the two principle kinds of brain activity at different levels of analysis. Brain activity measures of the kind elicited in the traditional brain mapping studies have always been in response to external event sequences in the decontextualized odd-ball paradigm (see Donchin, 1981; Languis and Miller, 1992; Wilson and Languis, 1990). In this paradigm, infrequent (or odd) events are embedded in sequences of frequent events. For instance, an auditory event-related potential (AERP) may be elicited by requiring "the subject to listen to intermittent low (1000 Hz) and high (2000 Hz) tones presented to both ears through headphones at a ratio of 5:1 respectively" (Wilson and Languis, 1990, p. 270). In these studies, the infrequent event elicits a positive wave form approximately 300 ms after the presentation of the rare event (P300). According to Donchin (1981), "on the basis of data like these we can assert that surprising events elicit a large P300 component. But the statement that P300 is elicited by surprising events is an assertion about the antecedent conditions of the P300. It tells us nothing about the process, or processes, manifested by the P300. Thus, it does not constitute a theory of P300" (p. 498). By specifying the kinds of brain activity involved (e.g., surprising events cause MCFs and frequent events tend to cause OBA), biofunctional cognition provides such a theory not only to the extent that it predicts exactly the kind of data that the odd-ball framework produces, but also to the degree that it explicitly articulates a particular theory for conceptualizing the mutual grounding of environmental, behavioral, neural, and genetic levels of analysis (Scarr, 1992, 1993):

> Some neuroscientists assume that slow electrical activity is passive or epiphenomenal (see Jasper, 1981); others maintain that mental functioning occurs against the background of random brain activity; and still others assume that activation in the nervous system occurs against a background of inhibition. The double-activity functioning hypothesis implies that the brain might produce two different kinds of electrical activity, one associated with OBA (or thematic knowledge [creation]) and one with MCF (categorical knowledge [creation]). [Iran-Nejad, Marsh, and Clements, 1992, p. 488]

The frequent sequence of events in the odd-ball framework produces a ground of ongoing brain activity, albeit one very limited in scope, in the context of which momentary constellation firing caused by the presentation of the odd event generates the P300. Moreover, preliminary data we have gathered indicate that the magic eye paradigm may provide a better avenue than the odd-ball methodology to the different kinds of exogenous (e.g., discovery of the figure hidden in the magic eye picture) and endogenous (e.g., the emergence of an insight) brain activity postulated in biofunctional cognition.

Skill Acquisition and Wholetheme Reorganization of One's Intuitive Knowledge Base

One place where conduit metaphors of information-processing theory (Atkinson and Shiffrin, 1968) have been used successfully is in the area of skill acquisition research (Anderson, 1990; Fitts and Posner, 1967). This research suggests that skill learning is reproductive internalization of external knowledge by means of maintenance rehearsal of declarative knowledge. In the course of learning, maintenance rehearsal brings about automaticity, the end goal of learning and the defining feature of well-learned skills. Driving is often used as an example of how this occurs. Driving skill acquisition begins with declarative knowledge of driving. During the first *cognitive stage*, a relevant sequence of declarative knowledge (i.e., "shift into gear," "step slowly on the gas," and so on) is arranged by the instructor for the learner to internalize consciously. With time, mindful maintenance rehearsal of the internalized declarative knowledge sequence changes into procedural knowledge ready for production (or reproduction) on automatic pilot (Shuell, 1990).

This theory is as productive as it is rigorous. Its only notable weakness is that it is rooted in conduit metaphors. As a result, the theory implies that automaticity is synonymous with linear fluency — the automatized sequence of declarative knowledge runs its once mindful course mindlessly. In addition, the resulting linear procedure is also likely to defy grounding. To overcome these limitations, Iran-Nejad (1986) proposed biofunctional automaticity characterized by technical facility and intuitive flexibility. Biofunctional automaticity is not mindless. On the contrary, it is richly grounded in the intuitive self-awareness of the ongoing functioning of the nervous system, in which "cognition and affect are thus wrapped up with one another in the integrated process of self-expression" (Prawat, 1998, p. 217; Iran-Nejad, Clore, and Vondruska, 1981).

In order to show how this might happen, biofunctional cognition defines learning not as piecemeal internalization of external knowledge, but as wholetheme reorganization of the learner's own intuitive knowledge base through, optimally speaking, a series of self-guided insights (Iran-Nejad, 1994). Of course, the more one's intuitive knowledge base engages in wholetheme reorganization, the more flexible it becomes. This flexibility manifests itself in domain-specific technical facility or in domain-comprehensive intuitive flexibility. Therefore, far from consisting of a piecemeal sequence of mindful steps, learning how to drive mobilizes domain-comprehensive as well as domain-specific aspects of the brain's figure–ground navigation system into a temporary interest-creating discovery module (see above) that takes the learner through a somewhat uneven course of self-, as well as world-, discovery toward a fluid competence for driving. The result amounts to both technical facility and intuitive flexibility in driving. Thus, having learned and always driven on the asphalt highways in a sedan, an individual might readily adjust to the peculiarities of the sand dunes of a vacation resort for the first time in a very different type of vehicle. This is because the technical facility specific to the domain of driving is intimately grounded in the brain's figure–ground navigation system.

Neither is the technical facility to drive mindless. Rather, it is grounded in tacit intuitive self-awareness. To illustrate with yet another example, imagine driving a vehicle along a winding country road. On such a road, negotiating every curve presents its own unique challenge. We use our ongoing intuitive self-awareness of the sand on the asphalt to rely on the firm grip of the tire where it meets the road or of the smooth unpredictability of the ice under the tires to make instantaneous readjustments for an opposite course of action. Technical facility must be grounded in such a fashion to do justice to the simultaneous influences of multiple factors in multiple internal and external fronts. In driving, these multiple influences come from road conditions, the type of vehicle, the speed of the journey, the sprained ankle on the left foot of the driver, the fragile contents of the box on the passenger front seat, and so forth. The driver must use them simultaneously to determine on a continuous moment-by-moment basis exactly how much to turn the steering wheel, press on the gas, or put on the brakes. There is a wholetheme reorganization hiding at every turn waiting to be skillfully navigated or else! By contrast, for an experienced driver sitting in a stationary vehicle, it is impossible to determine ahead of time with any safe degree of accuracy how much to turn the wheel or press on the gas at a particular curve. The brain as a figure–ground navigation system is at its best when engaged in the act of figure–ground navigation. The difficulty experienced in the stationary position, on the other hand, is hard to explain in terms of the conduit-metaphor-based procedural automaticity that must be able to run its linear course with error-free predictability. Because technical facility of driving is authentically grounded in the brain's figure–ground navigation system and intuitive self-awareness, it has the performance quality of what Schön (1987) described as knowledge-in-action.

Sources of Self-Regulation and the Brain–Mind Cycle of Reflection

Recent developments in behavioral, cognitive, phenomenological, sociocultural, motivational, and metacognitive domains provide converging evidence to indicate the need for going beyond memory processes and toward a more complete picture of self-regulation (Corno, 1989; Hidi, 1990; Palmer and Goetz, 1988; Pintrich and Schunk, 1996; Zimmerman and Schunk, 1989). These developments have recently led to the conclusion that learning is a multisource phenomenon (Iran-Nejad, McKeachie, and Berliner, 1990). An intriguing question arises: How does the figure–ground navigation system regulate so many different influences occurring simultaneously at so many external and internal fronts? The biofunctional model implies that evolution must also have endowed the figure–ground navigation system with multiple sources of self-regulation (Iran-Nejad, 1990; Iran-Nejad and Chissom, 1992).

First, much of the brain's activity is regulated dynamically by the brain's own subsystems and microsystems. This dynamic (or brain-regulated) type of self-regulation can go on even without requiring allocation of conscious attention or effort from the individual person. This kind of self-regulation can explain the evidence, anecdotal or otherwise, of the kind suggested by widespread claims of problem solving during sleep (Cartwright, 1977; Feldman, 1988; Finke, 1995; Miller, 1984; Shepard, 1978). Similarly widespread are the reports of spontaneous changes in knowledge and memory. Consider the following quotation from Oliver Wendell Holmes' (1858) *The Autocrat of the Breakfast Table*:

> Put an idea in your intelligence and leave it there an hour, a day, a year without ever having occasion to refer to it. When, at last, you return to it, you do not find it as it

> was when acquired. It had domiciliated itself, so to speak — become at home — entered into relation with your other thoughts, and integrated itself with the whole fabric of your life. (p. 134)

Broudy (1977) reports that John Livingston Lowes remembers the above passage thirty years after reading it "in the form of something germinating and expanding . . . with white and spreading tentacles, like the plant which sprouts beneath a stone" (Lowes, 1927, p. 14). Such a truly "strange transformation," as Broudy characterized it, occurring "unwittingly," to use Bartlett's (1932) term for the phenomenon, lies outside the realm of conscious constructive elaboration. On the other hand, they are exactly the kind of spontaneous changes over time with which dynamic self-regulation deals. It is also the same kind of dynamic self-regulation that is responsible for the fluency of well-learned skills (Iran-Nejad, 1986) and for the self-propelling power of big ideas (Dewey, 1910/1933; Prawat, 1998). The critical difference between dynamic self-regulation and procedural automaticity is that the former is at its best with change and the latter is at its best with preestablished structure. Returning to the example of seeing, the well-camouflaged predator may be completely safe right in front of the eyes of the prey. But as soon as its spots shift, it has already lost its meal. Second, conscious attention is grounded flexibly in dynamic self-regulation. Being available during all waking hours, dynamic brain functioning is under indirect control of the individual person. Brain-regulated (or dynamic) and mind-regulated (or active) sources of self-regulation unite into a single figure–ground navigation system through what might be called the *brain–mind cycle of reflection*. What makes this cycle of self-regulation possible is the intuitive self-awareness grounded in the two kinds of brain activity and the resulting thematic and categorical knowledge discussed earlier.

It is important to reiterate that dynamic self-regulation is not mindless. How the brain–mind cycle of reflection engages the two internal sources of self-regulation may be illustrated by analogy to how the body itches and the individual person scratches. We cannot regulate the bodily processes behind the experience of an itch. The body itself regulates those processes, which cause, in turn, the creation of the self-awareness of the itch. Scratching the itch, on the other hand, is active because it involves the individual's, as opposed to the body's, conscious decision of whether or not to scratch. This dynamic-itching/active-scratching cycle plays a universal role in organismic self-regulation that is the core process of the brain-awareness/mind-reflection cycle called here the brain–mind cycle of reflection, for short.

The natural solution that the brain–mind cycle of reflection offers to the symbol-grounding problem opens new doors for the exploration of critical thinking and reflection. The biofunctional model reminds us of the severity of the symbol-grounding problem if the dynamic aspect of brain functioning is not directly considered in the brain–mind cycle of reflection. Left with active self-regulation alone, we would be left exposed to the usual dangers of elaborative processing: overelaboration, overabstraction, or overparticularization, all of which are tantamount to a sustained focus on trivial detail of to-be-remembered facts (Pressley, Wood, Woloshyn, Martin, King, and Minke, 1992; Woloshyn, Willoughby, Wood, and Pressley, 1990). Moreover, focus on constructive elaboration in specific domains would tend to leave out what is common across domains.

In the context of conduit metaphors, the problem of cross-domain commonalities may be addressed in terms of the abstract–concrete hierarchical structure of long-term memory. Thus, past research has studied the memory for the information-lean abstract (or higher level) knowledge, the information-rich concrete (or lower level) knowledge, or their interaction (see Alba and Hasher, 1983; Iran-Nejad and Ortony, 1984; Rumelhart, 1975). The idea is that the abstract represents what is domain-general or common to all domains. Unfortunately, abstract commonalities have been a slippery concept. Even abstract commonalities across the different applications of a single concept have been called into question (Anderson, 1984; Anderson and Shifrin, 1980; Ichimura, 1991). Because we tend to think in terms of particular domain schemas, it is extremely difficult for our active self-regulated processes to shake loose of the grip of domain-specific thinking to acknowledge the domain-comprehensive sources that do the real work in the background. This is because the focal consciousness that encapsulates domain-specific thinking causes attentional blindness to the domain-comprehensive functioning that goes on outside the realm of focal attention. The only course for focal attention to take is to proceed in the direction of overelaboration (or overdifferentiation), overabstraction (or overcomputation), and overparticularization (or overcontextualization). Story grammar research (Rumelhart, 1975) is a fine example of how domain-specific exploration in this direction can lead to isolation and fragmentation. Soon after this approach was launched by Rumelhart (1975) it turned into a popular research area. However, the very aspects that make stories what they are (e.g., their entertainment function) were the first to fall victim to overelaboration (Brewer and Lichtenstein, 1981). The research maintained its momentum until Black and Wilensky (1979) demonstrated what Wilensky (1983) called the flaw in Rumelhart's story grammar. What the story grammar approach left out were Berlyne's (1974) aesthetic factors — curiosity, suspense, uncertainty, excitement, and surprise — whose functioning is regulated directly by the brain and which play a central role in the domain-comprehensive perspective under consideration (Iran-Nejad, 1980, 1983; Iran-Nejad, Clore, and Vondruska, 1981; Iran-Nejad and Ortony, 1984).

The brain–mind cycle of reflection is a solution to the symbol-grounding problem. At the heart of this solution is critical reflection anchored in ongoing brain activity (which creates thematic knowledge), momentary constellation firing (which creates categorical knowledge), and their interaction. It is also anchored in two different kinds of self-regulation: active and dynamic. In addition, all of these relate to one another by means of intuitive self-awareness, which is the language with which the brain and mind talk to each other. Critical reflection may be viewed as the kind of constructive elaboration that is grounded in intuitive self-awareness of brain functioning. However, this kind of constructive elaboration goes beyond the mere act of making connections. In fact, describing the process of critical reflection as connection-making goes against the natural design of the brain–mind cycle of reflection, in which nothing salient is anything remotely like making connections.

Therefore, critical reflection is more aptly characterized as problem solving. The problems that critical reflection attempts to solve are too slippery and too complex to solve by means of linear connections. Schön (1987) stated that such problems "tend not to present themselves as problems at all but as messy, indeterminate situations" (p. 4). Iran-Nejad and Ortony (1984) identified two varieties of intuitive self-awareness that guide the process of critical reflection in problem solving — two qualitatively different sides to the coin of critical reflection. Critical thinking must involve a sense of *problem recognition* to enable the individual to detect what is unsettling about the situation at hand. It must also involve a sense of *solution recognition* to enable the person to detect answers when such present themselves (Iran-Nejad and Ortony, 1984; Schön, 1987). In biofunctional cognition, problem recognition and solution recognition are viewed, not as abstract procedures, but as salient aspects of the intuitive self-awareness that the brain creates on an ongoing basis (Iran-Nejad, Clore, and Vondruska, 1981). Real-world problematic situations have their own inherent uniquenesses, causing each one of them to defy any predetermined routines. This consideration led Schön to argue against the determinism of technical rationality and its tendency to rely on prescriptive techniques and finished procedures.

Summary and Conclusions

People may be said to search, find, select, organize, analyze, and apply the knowledge that is inside them, much like they would the objects in their surrounding world. They may be said to gain more knowledge in the same way that they acquire external objects or build new knowledge by making connections among isolated pieces of information much like they would build a house by piecing together building material. The conduit-metaphor approach has much in its favor if the goal is understanding the structural features of mental products. Consideration of alternatives such as biofunctional cognition must not be seen as suggesting that understanding the structural aspects of the mental software is any less important. What is problematic is if the analysis of mental software consumes all of our energies. In this spirit, biofunctional cognition opens the gate for a shift from the product to the functioning of the system, from knowledge-as-an-object to knowledge as intuitive self-awareness, from information processing to self-regulation, and from linear constructive elaboration to the brain–mind cycle of reflection.

In biofunctional cognition, different instances of a given concept are not associated by unit-to-unit connections, much like the wind of a rainy day and the wind of a sunny day are not associated by some kind of direct wind-to-wind connection. Thus, the different instances of the concept "held" as in *The rock held the door*, *The psychologists held a conference*, and *I held my breath* are not associated by any kind of linear unit-to-unit connection (see Anderson, 1984). Neither can one instance be processed into another by means of deletion, addition, or other kinds of product-to-product transformation. Rather, they each have their origin uniquely in their set of common domain-comprehensive sources much like different instances of wind are unique manifestations of a common set of forces. More generally, it might be said that concepts are not related by means of direct unit-to-unit associations. Rather, the way they relate may be more aptly described as indirect unit-to-context relations. How this implication of biofunctional theory is different from the perspectives that concepts are related to the extent that they share elements or by virtue of their family resemblances remains to be seen.

Learning in biofunctional cognition is not simple accumulation of knowledge. Neither it is building unit-to-unit connections among existing pieces of knowledge or fine tuning unit-to-unit organization of knowledge networks by means of product-to-product transformations. Rather, it is technical facility and intuitive flexibility to deal with change in increasingly diverse situations. This kind of learning may be characterized as wholetheme reorganization of the learner's own intuitive knowledge.

Biofunctional cognition suggests that the search for understanding knowledge and self-regulation must be interdisciplinary in all its manifestations. We cannot isolate for theoretical or empirical investigation the learning behavior, biology of learning, sources of self-regulation, affect, situatedness or contextual aspects, social organization, the contribution of culture, or the background of the learner. Neither should our search be guided by eclecticism of some unintegrated mixture of the above aspects. Rather, a truly interdisciplinary approach must be wholetheme in nature, one in which each aspect is naturally grounded in all others to form an authentic ecosystem.

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