How systems principles can serve as foundation for constructivist learning and teaching.

by Renate N. Caine

> *Just as the first half of the twentieth century was the age of physics, and the second half of the twentieth century was the age of biology, so the beginning of the twenty-first century is the age of brain-mind science.*
> Elkhonon Goldberg, (2001), p.23.

In the previous paper, Geoffrey Caine (2004) suggested that every human being is a living system, and that learning is what living systems do. If true, then there must be coherent rules or laws that explain learning and guide education. In an effort to identify these rules we (Caine and Caine, 1990) developed twelve systems principles of learning called Brain-Mind Principles of Learning. They describe a type of collective reality and identify how humans, as living systems, create meaning and make sense of their world.

WHAT QUALIFIES AS A SYSTEMS PRINCIPLE FOR HUMAN LEARNING?

Principles based on a systems view should meet four basic criteria:

1. *The phenomena described by the principle should be universal.*

It must therefore refer to phenomena true for all human beings despite individual genetic variations, unique expressions, and developmental differences.

2. *Research documenting any one specific principle should span more than one field or discipline.*

Since the principle describes a systems property, one would expect a valid principle to be confirmed by research that crosses multiple fields and disciplines.

3. *A principle should anticipate future research.*

It should be expected and anticipated that research will continue to emerge that refines and confirms a principle. In addition, a principle is a continuous work in progress, as long as human beings delve into the rules by which life exists. A principle is never complete in the sense that new perspectives and ongoing research will continually refine and prove the principle.

4. *The principle should provide implications for practice.*

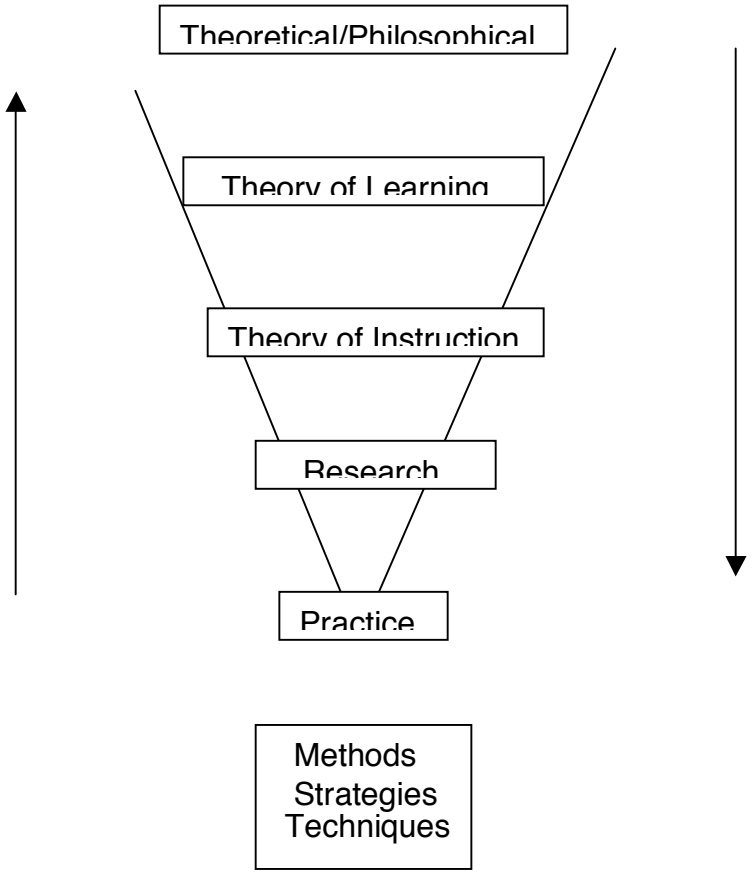
By their nature, principles are so general that they can not be expected to tell educators precisely what to do. However, effective learning principles ought, as a minimum, to provide the basis for an effective general framework that can guide decisions about teaching and help in the identification and selection of appropriate methods and strategies.

Our principles were first published in 1990 (Caine, R. and Caine, G.) and received their first expanded treatment in the orignal edition of *Making Connections, Teaching and the Human Brain* (Caine and Caine, 1991, currently under revision). They are as follows:

BRAIN-MIND LEARNING PRINCIPLES

1. All learning is physiological.
2. The Brain-Mind is social.
3. The search for meaning is innate.
4. The search for meaning occurs through patterning.
5. Emotions are critical to patterning.
6. The Brain-Mind processes parts and wholes simultaneously.
7. Learning involves both focused attention and peripheral perception.
8. Learning always involves conscious and unconscious processes.
9. We have at least two ways of organizing memory: a spatial memory system and a set of systems for rote learning.
10. Learning is developmental.
11. Complex learning is enhanced by challenge and inhibited by threat.
12. Each brain is uniquely organized

On the surface, the principles are deceptively simple, but in general they have met all four of the criteria set out above. Each systems principle summarizes a very large body of coherent research. Because they collectively describe an interconnected system, each principle is given equal weight and ultimately interacts and affects every other principle. We number them for the purpose of identification only. Each principle moves from the more global/theoretical to the specific in the following manner:



ONE EXAMPLE

We will demonstrate how principles are constructed by exploring one particular principle. It is known as Principle #11: *Complex Learning is enhanced by challenge and inhibited by threat accompanied by a sense of helplessness and/or fatigue.*

What is complex learning?

We originally described complex learning by relying heavily on Piaget's construct of formal operational thinking (Piaget, 1976). We also referenced O'keefe and Nadel's theory and research on the nature and function of the locale memory system (1987. It now seems to us that what is known as the executive functions represent an additional aspect of complex learning and expands on our prior synthesis. Ultimately we came to the conclusion that complex learning is essentially constructivist, and that constructivism engages the whole system. Accordingly, we now use the umbrella term "Brain-Mind constructivism" (Caine, G., 2004, unpublished manuscript).

Complex learning as defined by the brain's executive functions.

The executive functions refer to a number of functions housed largely in the frontal and prefrontal cortex of the brain (located primarily behind the forehead). This area coordinates and simultaneously integrates emotions, thinking, memory and body or physical movement (Molfese, L. and Molfese, V., Eds., 2002; Lyon, G. and Krasnegor, N. Eds., 1999).

E. Goldberg (2001) compares the executive functions to the role that an orchestra conductor plays. The conductor doesn't play an instrument or in any way do what the members of the orchestra are doing. Rather, he is in charge of how the entire piece of music comes together. He determines how loud the oboe plays, when the violins need to come to the foreground and as the conductor, he influences how the soloists are integrated. All of this is happening together as he moderates the volume, pace and rhythm of the music.

What the conductor does for the orchestra is roughly what the executive functions do for the brain. They combine elements of affect, self-regulation, working memory and inhibition in moment-to-moment action and decision making.

Although there is still some controversy surrounding the actual location and definition of executive functions, there is also significant agreement.

Boone (1999) suggests that the term "executive functions" refers to abilities involved in volition, planning, purposeful action and effective performance.

At the heart of the executive functions is "the ability to maintain an appropriate problem-solving set for attainment of future goal" (Pennington, p.586) which is also called working memory. Working memory refers to the ability to maintain plans and keep a goal in mind or "on line", in order to complete a specific project. Working memory also allows an individual to override an automatic response and shift problem-solving strategies to an alternate solution (also referred to as flexibility).

Samango-Sprouse (1999), summarizes four target behaviors that are now generally accepted. They include:

1. Planning (motor and time);
2. Decision making (across time and space);
3. Self-directed goal direction;
4. Monitoring and altering ongoing behavior to achieve a goal.

As we will see, the ability to deal with time or longer time horizons relies heavily on the executive functions.

In addition, the frontal lobes of the brain are considered to be the seat of our personality because this area integrates many functions including the emotions. Executive functions are believed to be involved in the highest levels of goal-directed behaviors and have become associated with behaviors linked to consciousness such as self-awareness, self-regulation, intentionality and altruism (Banyas, 1999).

Executive Functions allow an individual to operate independently and actively create and execute plans to solve problems. Denkla (1999) suggests that the executive functions are central to higher order cortical operations and have strong overlap with attention and memory.

What the executive functions allow students to do.

Individuals with highly developed executive functions can put things together and coordinate their thinking in order to apply what they know and have an impact on their world. For example, they:

1. *Have a better developed sense of time and space*. They can:
    - Set short term and long term goals and succeed;
    - Use time management and correctly assess needed action and sequence;
    - Search for successful strategies or resources;
    - Apply logic and "mathematical" thinking.

2. *Are more self directed.* They:
    - Persist under pressure;
    - Are more independent;
    - Know how to learn and how *they* learn (metacognition);
    - Can evaluate themselves.

3. *Possess greater flexibility.* They can:
    - Recognize and move beyond a simple stimulus-response reaction;
    - Shift their thinking on the basis of new information or data;
    - Recognize how things are connected and interrelated in other than a linear, sequential manner.

4. *Have greater social skills.* They:
    - Recognize emotional and social patterns and respond appropriately;
    - Recognize and reflect on their own behavior;
    - Recognize their own emotional states in the actions and experiences of others.

These students can think in terms of change over time and this makes a significant difference in achieving success. When students understand that effort over time results in

incremental improvement, they also tend to be more motivated. The thinking of less successful students tends to be more reflexive as they think in terms of all or none – being smart or not being smart, getting the "right" answer or not getting it "right". They don't see the possibilities or options that can lead to mastery over time due to expanded effort.

Complex learning then, defined particularly for this principle, refers to a broad synthesis of abilities that include formal operational thinking and the ability to deal with abstractions and complex relationships. It also includes the capacities attributed to the executive functions such as working memory, flexibility, self directed learning, affective intelligence and knowing oneself

What develops the executive functions?

Executive functions are not developed through memorization. And although the executive functions do not mature fully until the end of adolescence (and some speculate it is even later), they need to be engaged and developed along the way. When students are engaged in the search for meaning, and that search results in answers to questions they care about, then they are engaged in developing or using their executive functions.

Different types of decision making

Goldberg distinguishes between actor centered, adaptive decision making and what he calls veridical decision making. Actor centered adaptive decision making requires goal directed learning that emerges out of meaningful questions posed by the learner. "Actor centered" then refers to the learner who has a need to know or understand, "adaptive" refers to the learner's search for information or "best fit" relevant to an ongoing or immediate need. Such questions and answers are often mired in an uncertainty that must be resolved. Answers go beyond the concrete and have an emergent quality in that they are discovered not guaranteed. Goldberg suggests that it is the engagement of learners in this type of meaningful search for appropriate answers and solutions that more fully relies on, and develops, the executive functions.

He contrasts this type of learning with what he calls veridical decision making, which relies on finding, remembering or using an established truth. Veridical is closely associated with "verifiable" and relies on an answer that is either true or false. Most educational testing and teaching relies heavily on the accumulation of veridical knowledge and making decisions on the basis of correct or incorrect, i.e. true or false answers.

Perhaps a good way to distinguish the two is to say that actor centered adaptive decision making is about establishing "my truth" or deciding what action to take. This type of search is dynamic and often includes ambiguity and a sense of uncertainty. Veridical decision making on the other hand relies on executing a procedure or relying on a "truth" someone else established. One refers to the search for an answer, i.e. "how is this medication used in this case?" and the other refers to the formula or answer arrived at by someone other than the learner i.e., "this medication is applied in the following circumstances". Both may be useful but only the former requires the learner to search out an answer that engages actor centered adaptive decision making. It is the process - the searching itself that engages and develops executive functions.

Goldberg's concepts of actor centered adaptive decision making and veridical decision making provide a clear example of why we call this Brain-Mind constructivism. It adds evidence from the neurosciences that nicely fit Kauchak and Eggen's (1996) definition of constructivism:

> *[Constructivism is a] "view of learning in which learners use their own experiences to construct understandings that make sense to them, rather than having understanding delivered to them in already organized form…. Learning activities based on constructivism put learners in the context of what they already know, and apply their understanding to authentic situations." (Kauchak & Eggen, 1998, p. 184)*

Brain-Mind constructivism then is predicated on the notion that children need to engage in actor centered adaptive decision making while traditional education is predicated on

the belief that no decision making is needed or that the decision has already been made by another (expert). The latter type of decision is veridical.

By challenge then we refer to learning that is intrinsically compelling and actor centered.

Complex learning can be sabotaged in two ways.

1. The learning environment

One way has already been touched on and involves the almost exclusive reliance on veridical decision making. By definition this approach to learning and teaching ignores opportunities for students to engage in the type of challenging questioning and search for solutions that require the use of, or engage, the executive functions.

2. The unfortunate impact of too much or prolonged and persistent stress

Stress is a phenomenon familiar to most people. It is a heightened arousal reaction to some stimulus — be it an event, object, or person. There is now a substantial amount of information about the physiological processes at work (Selye,1978; Sapolsky, 1998; LeDoux, 1996; McEwen, 2001) . For example, the body creates the hormone cortisol in direct response to certain types of stress; and chronic stress is associated with high levels of cortisol in the body.

The hippocampus, the region of the brain associated with new learning in particular, is also the region most sensitive to cortisol and is negatively affected by high levels of the hormone (Sapolsky, 1998).

Not all stress is harmful. Indeed, life without stress is not possible. Hans Selye (1978) distinguished between the unpleasant or harmful variety, called "*distress*" (from the Latin *dis* = bad, as in dissonance, disagreement), and "*eustress*" (from the Greek *eu* = good, as in euphoria).

Stress associated with self efficacy or personal volition and motivation is actually essential for learning (Ornstein, R. and Sobel, D. 1987; Sapolsky, 1998; McEwen, B and

Schmeck, H., 1994; Peterson, C., Maier, S. and Seligman, M., 1993) *The deciding factor appears to be whether we see a solution to a problem and see ourselves as capable of resolving it*. In behavioral terms, it depends on who is in charge of the contingencies. It is the learner's answer to the question "Am I helpless or do I have some control?" that matters most.

How threat accompanied by a sense of helplessness and/fatigue affects the brain and learning.

Let us use a metaphor and compare the brain to an electrical power grid. Electric power grids connect electric power stations across a very large area (several states or throughout a country). The grid is interconnected in such a way that power stations (known as nodes) "speak" to each other in order to keep the grid balanced. If there is too much power in one station, that node sends some of its power to other stations that can use the added energy. On the other hand, if one station needs a great deal of energy because of high demand as during an emergency for example, the other stations in the grid give some of their energy away and lower their own energy level in the process.

The brain works something like that. In a relaxed and motivated individual, energy is available for many brain functions. Problems occur when human beings experience threat. Threat is fear accompanied by a sense of helplessness. When these conditions exist, the brain is designed to focus most of its energy on survival. Survival requires a quick, almost instantaneous response.

Just as in the electrical grid, this sudden surge of energy, required in order to respond to real or imagined threat, comes at a price. Some areas of the brain lose energy while those in charge of securing survival are charged. Areas in the brain that are minimized during threat include those that are not directly essential for survival and that process more slowly such as areas that govern reflection, thinking and analysis, interpreting social nuance and consciously analyzing a situation. These are abilities we have already identified as largely governed by the prefrontal cortex and the executive functions.

LeDoux used the term “low road” (1996). Caine and Caine used Les Hart’s term, “downshifting” (Hart, 1978). The Caines defined downshifting as “the psychophysiological response to threat accompanied by a sense of helplessness or fatigue.” (Caine, R. and Caine, G., 1994). The terms “downshifting,” “low road”, and “survival response”, are often used interchangeably. They refer to the same phenomenon.

Fatigue refers to the continuous buildup of stress hormones in the body. Sleep deprivation, over stimulation or continual arousal (constant change even if it is “fun”), lack of exercise, and physical imbalances (due to lack of water or food, being very underweight or overweight, emotional exhaustion and failing to take medication needed for proper functioning of the body) can all create stress. Over time stress does not just compromise learning, it also compromises health. Once the body is saturated with an overabundance of stress hormones, the survival response is more easily activated.

Conclusion

When in survival, human living systems revert to the tried and true — and old beliefs and behaviors can surface and take on a dominant role regardless of what information the context provides (LeDoux, 1996). Responses become more automatic and limited). There is less ability to access all that is known or to generate relevant options. The ability to consider subtle environmental and internal cues is reduced (Gruneberg and Morris, 1979). Individuals seem to be less able to engage in complex intellectual tasks, those requiring creativity and the ability to engage in skills attributed to the executive functions (LeDoux, 1996).

Under severe stress, behavior and thinking can become phobic in the sense that specific stimuli trigger instant, potentially inappropriate, and usually exaggerated responses. A great deal of new research on this subject is coming from what is known as post traumatic stress syndrome (PTSD).

The survival response functions along a continuum.

Mental states and the ability to learn

Daniel Siegel defines mental state as a particular "state of mind" and describes it as : "the cluster of brain activity ...at a given moment in time. This moment can be brief or extended. The repeated activation of states of mind as time goes by-over weeks, months and years-into a specialized, goal directed set of cohesive functional units is what we are going to call a "specialized self' or 'self state". (Siegel, 1999, p.230)

Although many researchers have studied and shed light on states of mind associated with stress, fear and helplessness (LeDoux,1996; McEwen 2001; Sapolsky, 1998), one individual in particular, Bruce Perry (2003), has presented what might be described as a survival continuum that is immensely useful for educators. He identifies a continuum of 5 specific mental states, each of which identifies areas of the brain that become most accessible and directly affect the learner's ability to think and learn.

Perry has developed a continuum ranging from a mental state called "Calm", to one of "Arousal", of "Alarm", of "Fear" and one of "Terror". Each of the mental states is defined by :

(1) Which areas of the brain are predominantly active;

(2) What kinds of cognitive processing is available (how well or what kind of thinking can occur);

(3) How the mental state affects the learner's sense of time or time horizons (We have already identified the learner's sense of time as a part of the executive functions and essential to complex learning).

Mental stage one - Calm and engaged

Perry's notion of calm is the "relaxed" aspect of what we call relaxed alertness. It is largely a consequence of feeling competent and confident. Only in the calm mental state does the learner access both the subcortex and neocortex (areas that include the executive functions). This is the state in which an individual can think in abstract ways (executive functions) and has a sense of time that includes the extended future (executive functions).

When calmness is accompanied by the engagement of the learner in something of interest (purpose and meaning), then relaxed alertness occurs.

Perry's continuum, then, describes what happens to human beings as they move further and further from the optimum state for learning.

Mental State Two - Arousal

Most children and adults find themselves In the Arousal state most of the time. In the Arousal state the most active areas of the brain are the limbic area (emotions) and subcortex. In the state of Arousal an individual tends not to be able to think beyond concrete terms based on right and wrong. They often fail to take appropriate risks and revert to old or "safe" behaviors. Anyone who has ever been a new teacher walking into a classroom — or has seen one — will know what this means. Interns often take weeks before they risk stepping out from behind the podium or desk, or before seeing students as individuals.

Mental State Three - Alarm

In the Alarm state the brain's most active areas are the midbrain (sensory information) and limbic area (emotions). Someone in the alarm state is primarily sensing danger and is responding emotionally using anger or withdrawal. Such an individual is concerned with the next few minutes and at the most, hours. Tomorrow and next week, let alone next year is not a concept they can grasp.

Mental State Four - Fear

In the Fear state the brain's most active areas are the Brain stem (involuntary activities) and midbrain. Someone in the fear state is still not thinking in the way most people define the term. In Dr. Perry's words these individuals are primarily "reactive" which means that they are very much in a stimulus-response or automatic mode. They have very little choice over their reactions. Their sense of time is limited to seeing things in terms of minutes or seconds. Most educators have encountered children in the Fear state.

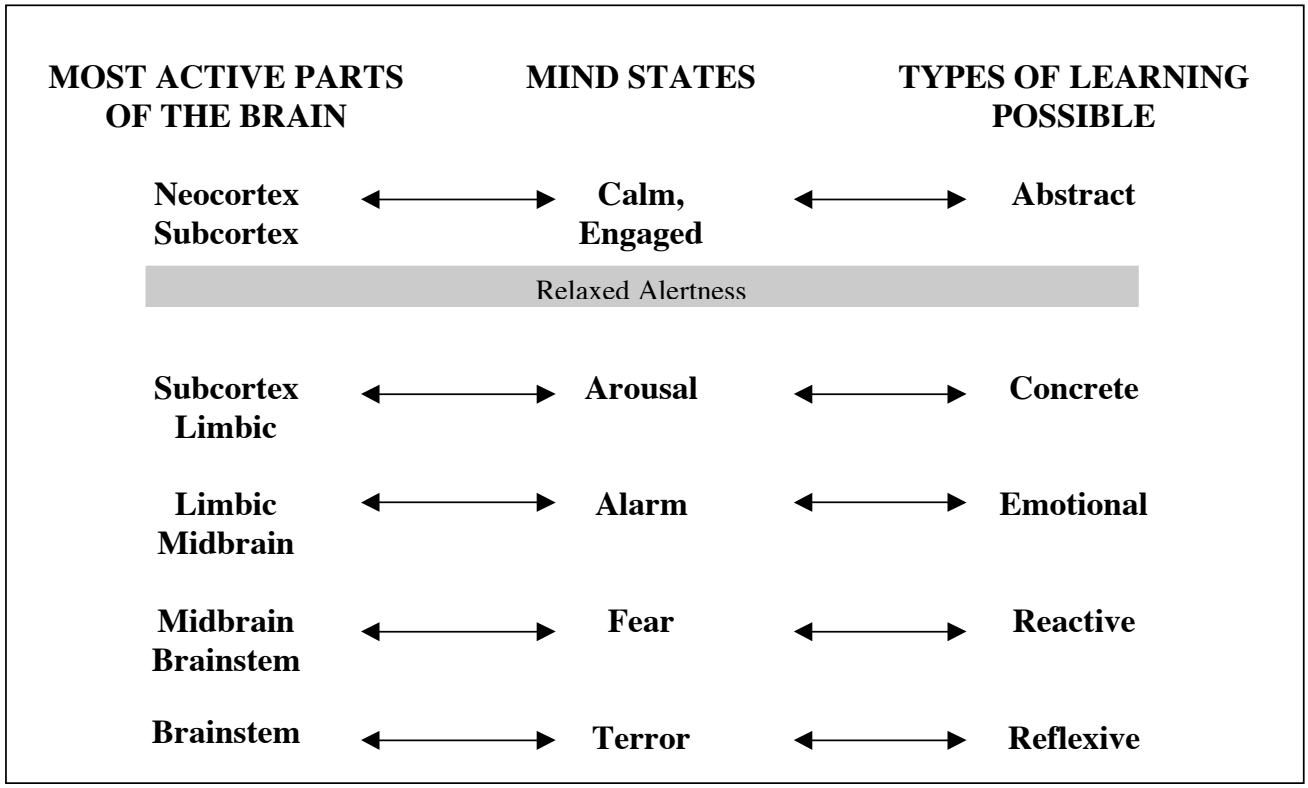
If you ask them to do something for tomorrow or remember the test on Friday you will not be heard.

Mental State Five - Terror

In the Terror state the individual is literally on "automatic" . The brain's most active area is the Brain Stem and the autonomic nervous system. Someone in the terror mental state really can not think in terms of how thinking is usually defined (figuring out how to do something for example). They basically react and their reactions are reflexive and totally out of their control. They do not refer to a past or future - they have in fact lost all sense of time. One can recognize individuals in a state of Terror when looking into their eyes. The expression we have found most useful is "there is no one home".

A word about behavior. Not all behavior in these more survival orientated states of mind (Alarm, Fear or Terror) leads to danger for others. Perry distinguishes between behaviors that are largely the result of an aggressively acted out or hypervigilant response, and a more internal fantasy like response that is "dissociative." The hypervigilant students can be expected to become increasingly aggressive, as they shift along the continuum from arousal to terror. On the other hand, students who tend to internalize their responses. move along the dissociative continuum and increasingly lose contact with reality. Educators often fail to recognize these students because they tend to be quiet and prefer to minimally do as they are told and work hard at protecting their anonymity.

The diagram below illustrate these relationships:



Adapted from B. Perry et. Al.

The bottom line is that optimum learning takes place when the learner is both relaxed and engaged, not alarmed, fearful or in terror. Some arousal is also necessary, but not the constant sort of hyper-arousal experienced by so many children and many teachers.

Individuals who are in the survival oriented mental states, particularly those who function there most of the time, tend to need a great deal of concrete information and require lots of practice and rehearsal. They want clear descriptions, need more support and advice, and are frustrated by having to solve problems that rely on the need to search for creative or hypothetical responses or solutions. The latter represent the essence of actor centered adaptive decision making. Using their executive functions for long term planning is more difficult as well. Educators need to do everything that they can to help students increase their sense of competence, confidence and meaning or purpose. Gaining confidence for

these students, at least initially, can mean that students need to be engaged in structured exercises that focus on memorization.

Moreover, there appear to be two different kinds of effects: an ongoing weakening of the system under continuous threat, and the sudden debilitation that occurs in times of crisis. Countering the above requires an environment that creates a continuing and appropriate degree of relaxation that maintains the system in a state of well-being generally (maintains appropriate stress responses as measured by stress hormone levels throughout the day). The other requires experiences that engage the eustress, or excitement, that accompanies an appropriate degree of personal challenge, and results in a general sense of competence and confidence.

CHALLENGE AS INTRINSIC MOTIVATION

Challenge refers to the personal search for meaning or engagement in learning which is of relevance to the learner. New learning must in some way connect to what the learner knows and wants to do or know more about. What matters, then, is that educators master the ability to access intrinsic motivation in students. In part, this means that teachers must help them relate to what is being studied by eliciting their own questions and linking to what is meaningful to them.

A more thorough discussion of motivation is beyond the scope of this paper. It would require discussion of such issues as self-efficacy (Bandura, 2000), the links between emotions and attention (Panksepp, 1998), the impact of extrinsic rewards on creativity (Kohn, 1999) and the nature of what Gopnik, Meltsoff and Kuhl call the explanatory drive (1999).

Our conclusion however is that challenge related to personal meaning and relevance is critical to building success, confidence, and practical intelligence. Challenging students means engagement in learning that has students stretch so that the range of situations in which they can function effectively continually increases. This is best explained by Vygotsky's "Zones of Proximal Development" (1978). Beyond the obvious point, that

stress associated with excessive control by others and a feeling of helplessness contributes to more restricted mental functioning, many factors support a sense of challenge:

- Ownership and sense of control over learning.
- A general sense of competence and confidence built on past experiences
- Positive social bonding,
- A sense of hope and positive expectancy;
- A belief in a world that makes sense;
- A sense of playfulness, joy,
- Respect for others and respect for self ;
- Self-discipline related to the capacity to delay gratification.

These are the very capacities lost in the survival state. Although literature, the arts, and our own experiences and research indicate that downshifting is an everyday phenomenon, more research is needed form the neurosciences and physiology. In particular, there is a need to understand the physiological differences between threat and challenge. The fact is, however, that there is already sufficient consensus in the literature to make the decisions about changing education that have to be made. We are not arguing that learning will only take place in some sort of ideal or perfect atmosphere. What we advocate is an atmosphere that consistently empowers students.

This Brain-Mind Learning Principle then, meets the qualifications set out at the beginning of this paper. The phenomenon is universal, supporting research spans multiple fields and disciplines, current and future research can be expected to continue to shed light on the principle, and it provides implications for practice.

THE DANCE OF THE TRIPLE HELIX: IMPLICATIONS FOR CONSTRUCTIVIST EDUCATION AND INSTRUCTION

The 12 Brain-Mind Learning Principles lead to the conclusion that educators must understand and master three continually interactive elements that are essential to constructivist learning and teaching.

1. We call the first element "Relaxed Alertness" and it refers to the optimum psychophysiological state in the learner and describe the environment that creates it. We define it as learning accompanied by a sense of competence, confidence, meaning and purpose.

2. Because the brain is designed to learn from experience and naturally searches for meaning, we advocate teaching and learning environments that create challenging experiences for learners. We call this "Immersion in Complex Experience".

3. Because this type of learning is dynamic and applied to actor centered questions, the role of the teacher changes. The teacher becomes a constant and vigilant questioner. This aspect we refer to as "Active Processing".

We describe the practical applications emerging out of the 12 Brain-Mind Learning Principles and the three elements in a book to be released later this year.

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