Mind, Brain, and Education: A Systemic Perspective

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Dear Colleague,

This working paper provides a sketch for a number of publications on Systemic Cognition and Education (SCE), its foundations, and its applications in curriculum development and student and teacher education. SCE is a generic pedagogical framework that stems from my work on Modeling Theory in physics and science education and from reliable research findings in neuroscience, cognitive psychology, and education.

I would greatly appreciate your taking the time to read this paper critically, and to get back to me with your valuable feedback at: halloun@halloun.net.

Please feel free to share the paper with interested colleagues, and to refer to it in any work. You may then gratefully cite it as:

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Sincerely,

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Our mind and brain affect each other and determine the way we learn in any setting. Formal education is supposed to help students make the best of their mental and cerebral faculties and potentials, and empower them for lifelong learning and continuous success in life. To this end, teachers, students, and all other stakeholders need a coherent pedagogical framework to guide their thoughts and actions in all scholastic respects. The framework should emerge from what reliable, yet still disparate, research in pertinent fields tell us about our students, especially in neuroscience, cognitive psychology, and education. In particular, it should conform to reliable findings on how our students actually are and think at specific school ages, what they can accomplish at a given age, and how they can realistically evolve throughout the years.

This article provides an educator's interpretation of research findings he knows about in the fields in question, and subsequently proposes an outline of a pedagogical framework that is meant to serve the above purposes. The interpretation comes through specific conceptual lenses and leads to a systemic perspective on mind, brain, and education that may contribute to bringing researchers and practitioners in these fields to some common grounds, at least in relation to the proposed framework.

Recent developments in neuroscience are bringing us closer every day to a solid understanding of the human brain and mind, and to reliable lenses through which we can examine the abundant findings of many decades of serious research in cognitive psychology and education. Some laudable efforts have been made in the last decade to reap the fruits of these developments in education, but these efforts had so far limited and localized impact (Hruby, 2012; Knox, 2016; Schwartz, 2015; Shrag, 2011). A transdisciplinary field has emerged in the process that is supposed to bring together neuroscience, cognitive science, and education because of the conviction that for "scientists to carry out useful research for education and for teachers to optimally educate based on research evidence require interweaving the perspectives of research and practice" (Fischer et al., 2007). The new field was given different names including neuroeducation, educational neuroscience, and mind, brain, and education (MBE). Yet, and because "MBE spans several traditional disciplines, individuals within it often hold differing and potentially conflicting expertise, perspectives, and knowledge", Knox (2016) argues in agreement with others, and continues that translation is needed among "research questions, goals, and findings between education and neuroscience in the pursuit of usable knowledge". Along the same lines, Hruby (2012) had argued that, among other things, the new field requires "careful and explicit attention to intellectual coherence", which would help "that diverse scholars and professionals may communicate findings and insights consistently across fields".

This article proposes, from an educator's viewpoint, an overall perspective on brain, mind, and education that lays the ground for a generic pedagogical framework, and that would hopefully facilitate negotiations among concerned experts and contribute to bringing coherence to MBE. The proposal comes from an interpretation of MBE related research through conceptual lenses derived from what physical science and philosophy of science tell us about the physical world we live in, and what cognitive science tells us about patterns of thought and practice that distinguish accomplished professionals (experts) from apprentices or novices (students of all levels).

The proposed perspective is grounded in systemism, a paradigm whereby the world within and around us is conceived as a world of dynamic systems that may interact with each other and affect the way each system is, operates, and evolves. An important faculty of the human mind is to constantly generate conceptual representations of the physical world, including our own selves, that would help us make sense of this world and devise conceptual and physical means for improving the quality of our lives and, hopefully, the world we live in. One such representation is the idea of a system as a set of elements, with particular properties of interest, that interact in well-defined ways under specific conditions to serve specific functions or purposes in specific domains.

The article comes in six sections and a short conclusion. It begins with a brief discussion of systemism, and then of humans as learning systems. It follows with a discussion of brain and mind as cognizant biological and cognitive systems respectively, and subsequently with specific implications on systemic education. The last section provides an outline proposal of "Systemic Cognition and Education" as a generic MBE-based pedagogical framework.

The first section argues that a systemic view of the world around us allows us to better make sense of this world, and especially of the patterns that predominate therein, from the astronomical scale of galaxies down to the microscopic scale of atoms and neural networks in the human brain. Such a worldview is also meant to enhance the efficiency of our transaction with concrete objects and to bring cohesion and coherence to our knowledge of and about the world. The argument is further made that all these objectives are best realized when systems are conceived in middle-out structures between big pictures (patterns, in particular) and elementary details, and when they are systematically put together in accordance with a six-dimensional schema for specifying system framework, scope, structure, ecology, operations, and outcomes.

The second section defines learners as dynamic systems for knowledge construction and deployment, and illustrates with an example that serves the discussion in subsequent sections how knowledge in experiential learning emerges from a realist-cognitive transaction between a learner and objects of learning with the possible assistance of some learning agents in a surrounding environment.

The third section presents a biological model of the brain as a dynamic, complex system composed of six distributed neural systems (relay, perceptual, motor, affective, rational, and epistemic) each of which serves well-defined functions in experiential learning that involves transaction with concrete objects of learning. This complex system allows sensory data processing and storage of emerging information through bio-chemical constituents and electro-chemical operations that involve the orderly formation of perceptual and conceptual images of the objects in question. The process begins with the unconscious filtration of sensory data in the relay system of the brain and formation of a perceptual image of each object. This image is then unconsciously analyzed in the perceptual system and broken down into unimodal information packages that are gradually synthesized afterwards in order to make up a conceptual image of the object. The synthesis begins unconsciously and then proceeds with conscious regulation carried out with the adduction of prior knowledge from memory under a number of metacognitive controls the most important of which are attention and particular emotions discussed in this section.

The fourth section retakes the formation of perceptual and conceptual images from a pure cognitive perspective in the mind system. Reiterative helicoidal cycles are discussed that gradually develop the images in question and sharpen the conceptual image by correspondence to objects of learning and prior knowledge in order to make sense of those objects and bring about desired learning outcomes in memory. Transient and sustained learning in short term memory and long term memory respectively are discussed with a new dynamic perspective on short term memory that encompasses what is known in the literature as working memory and highlights long term memory processes that are of prime importance to meaningful and sustainable learning. Processes include encoding, consolidation, storage, and retrieval of information under certain metacognitive controls that focus attention on lean systemic aspects of objects of learning and keep regulating the conceptual image insightfully until it brings any learning experience to its desired ends with the least cognitive load and the highest cognitive efficiency possible.

The fifth section draws implications from the discussion above to formal education. The argument is made for systemic education whereby an educational system is designed and operated at all levels as sets of interacting systems, including learners, teachers, and various other learning agents, and curricula are explicitly conceived and deployed in the context of systemic pedagogical frameworks. “Systemic Cognition and Education” (SCE) is proposed in the sixth section as a generic MBE-based framework that is meant to empower learners at all levels with dynamic systemic profiles for lifelong learning and success in all aspects of life. To this end, SCE calls for course materials and pedagogical practices to respect and take advantage of the systemic nature of the human brain and mind so as to promote meaningful and sustainable learning, and bring about well-rounded citizens with progressive minds, productive habits, profound knowledge, and principled affects (4P profiles).

1. Systemism

Our knowledge of and about the world is the result of transaction between physical realities (humans included), as they exist in the real world independently of how we might perceive them, and the rational realm of our human mind (Halloun, 2004/6). According to Johnson-Laird (1983, p.402), “our view of the world, is causally dependent both on the way the world is and on the way we are”, and, according to Lakoff and Johnson (1980, p. 163), properties we attribute to physical objects “are not properties of objects *in themselves* but are, rather, interactional properties, based on the human perceptual apparatus, human conceptions of function, etc.”. Similarly, Bunge argues that empirical experience “is not a self-subsistent object but a certain *transaction* between two or more concrete systems, at least one of which is the experient organism. Experience is always of *somebody and* of *something*” (Bunge, 1967, p. 162, italics added), and the resulting knowledge “is attained jointly by experience (in particular experiment) and by reason (in particular theorizing)” (Bunge, 1973, p. 170).

In the words of Bachelard (1949), what we know about the world results from a marriage between realism and rationalism, and, according to Poincaré (1902), things gain their significance from realist and rational perspectives only when related to each other. An entity, whether physical or conceptual, has little significance, if existing in isolation from other entities. The entity gains significance when it interacts with, or when it is related, to other entities in a well-defined structure. For instance, a bunch of stones has little importance and utility when piled up in a heap. The stones become far more important when used in constructing a wall, and even better, a house. It is how the stones are stacked, how they are related to each other, that turns the heap into a significant and useful structure. The same goes with Lego pieces. The same pieces originally scattered in a box may turn into a meaningful shape like a vehicle or an animal, depending on how we put them together, i.e., on how they relate to each other. Thus the same entities can result in different structure and function (utility) depending on how they

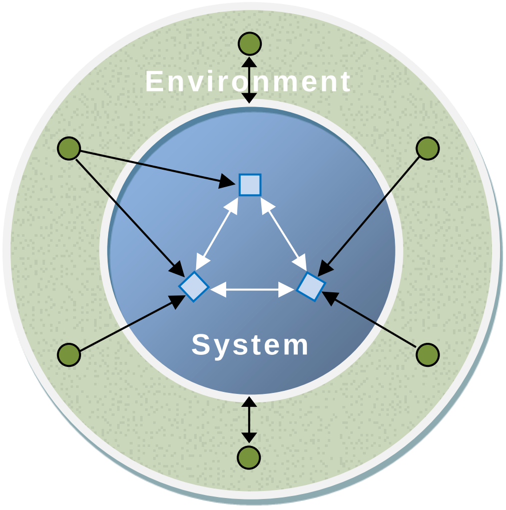

Figure 1. System structure.

The boundaries of a system and its environment are primarily determined by the purpose(s) the system is supposed to serve. The boundaries may then be conveniently delineated so as to account for certain entities and/or interactions of primary interest, and not others, in order to optimize what we are trying to achieve with the system (Halloun, 2004/6). Sometimes, these boundaries are delineated so that the system consists of a single entity with no internal interaction, and at other times, to embody all entities of interest inside the system so as to end up with an isolated system that has no environment to interact with. There are also times when we would be interested in specific interactions but not others within the system or with its environment. The arrows in the figure depict three such instances. The two-sided arrows between system *constituents* (entities inside the system depicted by squares) indicate an interest in *mutual inter*actions or relationships between the connected entities. The one-sided arrows between certain *agents* in the environment (entities outside the system depicted by disks) and constituents of the system indicate an interest only in the *action of* those agents on designated constituents, but not in the reciprocal action of constituents on agents (sometimes called reaction). The two-sided arrows between the system boundaries and agents in the environment indicate an interest in certain *mutual inter*actions between connected agents and the system as a *whole* (thus in the synergetic impact on the environment of all elements in the system acting together, and not the impact of individual system constituents).

are related to each other. Similarly, the same relationship may result in different outcomes when established between different entities. For instance, no two married couples enjoy exactly the same life together under wedlock.

Such relationships, functions, and outcomes are best conceived in the framework of systemism, i.e., when both the real world of physical entities, humans and their brains included, and the rational realm of our mind are conceived as systems, or parts of systems, of well-defined characteristics. Philosophers and cognitive scientists have long argued that a systemic worldview is optimal for meaningful understanding of ourselves and the world around us, from the tiniest details to the big picture in any experience we might be engaged in (Bunge, 1967, 1973, 1979, 1983 a & b, 2000; Casti, 1989; Gentner, & Stevens, 1983; Giere, 1988 & 1992; Harré, 1970; Hempel, 1965; Hesse, 1970; Johnson-Laird, 2006; Johanessen, Olaisen, & Olsen, 1999; Lakoff, 1987; Laszlo, 2015; Liu et al., 2015; Nagel, 1979; Wartofsky, 1968). Research in cognitive psychology reveals that accomplished people, especially professional experts, are distinguished from other people more in the way they organize knowledge than in the type and amount of knowledge they hold in mind, and more in how they systematically deploy generic skills that cut across various professions than in how they follow idiosyncratic or profession-exclusive heuristics. System-based organization (model-based, in science, scientific models being conceptual systems) comes in this respect among the most effective and efficient for structuring content knowledge, if not the optimal ones, and systemic thinking holds a similar upper standing when it comes to process knowledge (Assaraf & Orion, 2005; Bachelard, 1934; Bower & Morrow, 1990; Bunge, 1979, 2000; Čančula, Planinšič & Etkina, 2015; Clement, 1989; Chi, Feltovich & Glaser, 1981; Giere, 1992 & 1994; Glas, 2002; Halloun, 2004/6, 2007, 2011; Hmelo-Silver & Pfeffer, 2004; Hmelo-Silver, Marathe, & Liu, 2007; Johnson-Laird, 1983, 2006; Reif & Larkin, 1991; Rodriguez, 2013; Vallée-Tourangeau & Vallée-Tourangeau, 2014).

A system has been defined in a variety of ways in the literature, but they all converge on that a system may consist of one entity (if simple) or many entities (if compound) confined within well-defined boundaries. The constituent entities, and thus the system, may be either physical, if consisting of material objects, or conceptual, if consisting of abstract elements (e.g., scientific models). Convergence in the literature is also on that entities inside the system interact with each other (or are rationally related to each other) and, individually and/or collectively altogether, with entities located in the system environment outside the system boundaries (Fig. 1), so as to serve specific purpose(s) and bring about specific outcome(s).

We define a system of any sort in accordance with a six-dimensional schema that specifies the system's framework, scope, structure, ecology, operation and outcomes (Fig. 2).

Figure 2. System schema.
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1. The *framework* of a system consists of: (a) all premises (assumptions, principles, value system, etc. that are often spelled out in the paradigm of a professional community), and (b) strategic choices that guide the specification and reification of all other five dimensions.
2. The *scope* of the system specifies: (a) its *domain*, or the field or area in which it exists and is of importance and the pattern there which the system is an instance or a part of, and (b) its *function*, or the specific purposes it serves in that domain.
3. The *structure* of the system specifies: (a) its primary constituents, i.e., physical or conceptual entities inside the system that significantly affect its operation and outcomes, and (b) how these constituents interact with (or relate to) each other.
4. The *ecology* of a system specifies: (a) all primary agents in its environment, i.e., physical or conceptual entities, systems included, outside the system that significantly affect its structure, operation, and outcomes, and (b) how system and environment interact with (or relate to), and affect, each other.
5. The *operation* of a system is about all processes which constituents, and/or the system as a whole, might be engaged in on their own and/or under external intervention from the environment of the system, in order to serve the function of the system following specific rules of engagement.
6. The *outcomes* of a system consist of all actual products, events and phenomena (and/or services, when the system is, say, of social or industrial nature) which the system brings about (reified purposes) on its own or in concert with other systems.

A systemic perspective on the physical world allows us, among others: (a) to readily grasp the big picture, as well as the minute details in a given situation, and efficiently move between the two, and (b) to better understand how specific entities in our world interact with each other to bring about certain events and phenomena (outcomes), whether these entities and outcomes are considered in isolation from the rest of the world or as instances of universal patterns (Fig. 3). Patterns are structural or phenomenological regularities in space and time. They predominate in the universe, from the microscopic to the astronomical scales, which makes our world interesting and comprehensible. The day and night recurrence and season cycles on Earth are examples of patterns, and so are the morphology and life cycles of humans and other species.

The mentioned earthly patterns are best understood in the context of our solar system (or the Earth-Sun subsystem), and the life patterns in the context of the species' ecological systems. Patterns also predominate in our thoughts and memories as we shall see later, and we have a natural tendency to look for patterns in the world around us, and even to rationally impose patterns on what we perceive in this world or conceive about it. A systemic perspective on the real world allows us to efficiently identify patterns of interest in this world and to rationally conceive those patterns and readily integrate corresponding knowledge in our memories.

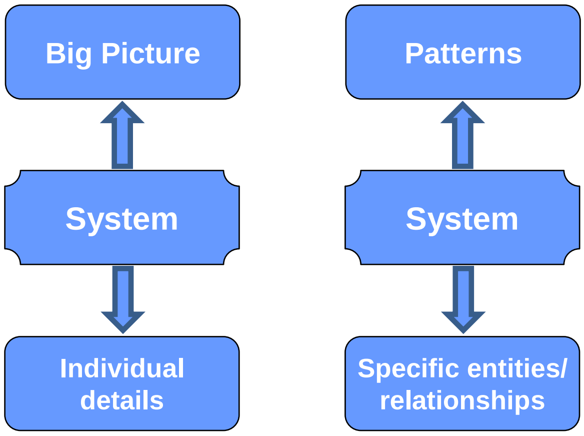

Figure 3. Systems in the middle-out hierarchy between the big picture and individual details in a given situation, and between universal patterns and local or specific entities and/or relationships between entities.

As indicated in Figure 3, systems occupy the middle of the rational hierarchy between a big picture (that may be a universal pattern) and specific details in a given situation. According to Lakoff (1987), humans organize their knowledge in middle-out structures whereby basic and most fundamental structures occupy the middle of the rational hierarchy between individual entities and the corpus of knowledge pertaining to those and similar entities. Systems, as we see it, are such basic structures. For example, a typical and crucial corpus of knowledge consists in science of a given theory or set of theories, and, in languages, of the various types and genres of discourse (or written text). A conceptual system in science, and more specifically a scientific model like Bohr's model of the atom, is to theory (the big picture) and concept (detail) what an atom is to matter and elementary particles. Each elementary particle at the bottom of the structural hierarchy is essential in the structure of matter at the top of the hierarchy. However, the importance of an individual particle cannot be realized independently of that particle's interaction with other particles inside an atom. It's the atom in the middle of the hierarchy and not elementary particles that gives us a coherent and meaningful picture of matter, and it's the atom that displays at best the role of each elementary particle in matter structure. The same goes for language. A sentence is a conceptual system that stands in the middle between discourse (or text) at the top of the hierarchy and phoneme (or even word) at the bottom. The sentence gives us a coherent and meaningful picture of any type of discourse, while, through corresponding semantics and syntax, it displays at best the meaning and role of each word in discourse structure (Halloun, 2001a, 2004/6, 2007, 2011).

A systemic perspective on the world allows us to bring cohesion and coherence to this world, as well as to our own thinking, and to understand certain aspects of this world that may not be easily conceived – and perhaps that may not be conceived at all – without such perspective. Such is the case, for example, with wholeness and holism. *Wholeness* is, for us, about the impact of any given entity or interaction in a system on the entire system. Every constituent of the system interacts with (or is related to) other constituents and somehow affects the state of the entire system. Any change in any given constituent or in any given interaction or relationship between two constituents results in a change of the entire system. Such a global impact can best be conceived and explained in the context of a system as a whole and not in terms of any clusters of relationships. *Holism* is, for us, about the added value that a system as a whole brings to its constituents and the surrounding environment through emergent properties and synergetic functions. In a sense, a system is greater than the simple sum of its parts. It brings about certain outcomes that may not be attributed to its individual parts and that may not be fully understood and appreciated by simply breaking the system into such parts (by analysis or following a reductionist approach). A system has emergent properties and synergetic functions. Emergent properties are properties of the system as a whole that cannot be attributed to any of its individual constituents (e.g., the shape of a house made up of stones and of an object made up of Lego pieces). Synergetic functions result from the interactions or relations among all constituents that lead to a system impact (effect) that is greater than the sum of impacts of its individual constituents (e.g., the dwelling made possible by the stones and other constituents making up a house, and the offspring of a married couple and the family they make up together).

For further illustration of wholeness and holism in the sense described above, consider the human body, a complex system consisting of many systems (or subsystems) including the respiratory system and the nervous system. Each of these systems serves a specific function in the human body and affects other systems. For instance, the respiratory system serves, among others, to provide necessary oxygen for various cells in the body. The nervous system, especially the brain, serves to generate and control human perception, thoughts, sentiments, feelings, memories, and actions. Various bodily systems work in tandem to sustain life (an emergent property that cannot be attributed to any single system alone), and to allow a person produce ideas and artifacts that neither system can produce alone (synergetic processes and outcomes). Similarly, ideas cannot be generated in the mind unless other systems like the respiratory system sustain the brain structure and operation. No other structure but the complex *system* that is the human body in its wholeness can bring about such holistic outcomes.

A caveat is quickly due at this point. Wholeness and holism, as we see them, do not deny the importance of individual constituents of a system within and outside the context of the system. They also do not necessarily imply a certain determinism or irreversibility in the state of system and constituents, especially not when of human or social nature. Under propitious conditions, a system may change its evolution course, and may as well recover from certain induced changes and return to its original state.

2. The human learning system

We are constantly engaged in learning, i.e., in developing our knowledge and skills, and changing the state of our mind (our memory) in certain respects, whether consciously or not, purposefully or not. Every time we interact with the world around us, we develop our knowledge about the entities we interact with in this world, as well as about related entities that may not even be directly exposed to us then. More precisely, we develop our "content" knowledge about these entities, knowledge that consists of all "factual" information and conceptions (concepts, laws, theorems, and other relations and abstract entities) we develop about the entities in question. Meanwhile, we may also develop some "process" knowledge, knowledge that consists of reasoning and/or motor skills, and that involves some emotions and other affects about the entities in question and the entire learning experience.

The learning experience with given entities, hereafter called "objects of learning" (OL), is a transaction between the learner, on the one hand, and these entities and the surrounding environment on the other. The transaction proceeds in ways (operation) and results in new knowledge (outcomes) all of which depend especially on the following factors (Fig. 4):

1. The actual purposes set for the learning experience.

2. The current physical (anatomical) state of the learner's brain and the ease and efficiency with which concerned cerebral parts interact with each other.

3. The current anatomical state of the learner's perceptual and motor organs, and of the peripheral nervous system that connects these organs to the brain.

4. The current state of mind of the learner (mental state), including the overarching framework that guides the learning experience, pertinent content and process knowledge in memory, and mnemonics s/he resorts to for accessing this knowledge, along with the person's emotions, dispositions, and other affects.

5. The actual state of the object(s) of learning which the learner is interacting with and learning about, and that might be of concrete or abstract nature.

6. The state of "learning agents", i.e., entities other than OL that the learner is engaging in the experience and interacting with, and which may be of human nature (other people who might be participating in the learning experience) or other physical nature (including employed tools and accessed information sources, if any).

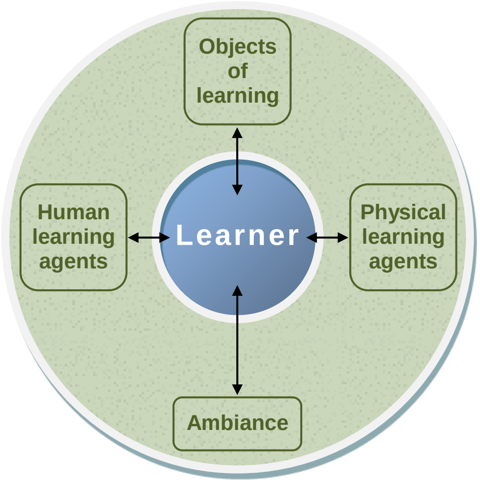

Figure 4. A system perspective on experiential learning, i.e., learning through transaction with the environment.

A learner (knowledge construction system) interacts with various entities in her/his environment. These include: (a) the objects of learning, i.e., various entities that the learner is exploring, (b) human learning agents, i.e., other people involved in the learning experience, and (c) physical learning agents, i.e., instruments and/or information sources the learner might resort to. Interactions within the learner-system (shown in Fig. 8) and among various entities in the environment are not depicted for simplicity and aesthetic purposes.

7. The overall "ambiance" of the environment, which includes any environmental entities (e.g., furniture) and properties (e.g., temperature) that might have a concomitant effect on the learning experience.

8. All internal and external interactions and operations which the learner is engaged in during that experience.

One may thus easily notice that the learning experience outlined above is systemic in the sense described in the previous section, and that the learner is actually a learning system that follows the system schema introduced there (Fig. 2). This particular systemic experience is an *experiential* learning experience that involves first hand interaction (transaction) with objects of learning (OL). Those objects may be concrete, i.e., of physical nature, like certain plants in nature, or otherwise abstract, like semantics and syntax, ethics and values. Learning may still take place in para- or non-experiential settings that do not involve direct interaction with OL, and may then primarily result in content knowledge and reasoning skills but not necessarily motor skills. Para-experiential learning relies on specific sources that provide us with some information about OL (e.g., textbooks, digital media, or "knowledgeable" people). Non-experiential learning occurs through intrinsic thoughts (e.g., inferences from existing knowledge) in isolation from any interaction with the outside world (Fig. 5). In the following, we concentrate our discussion on

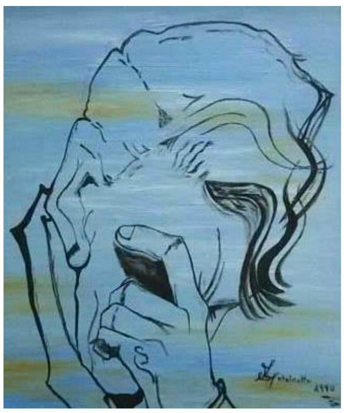

Figure 5. Thinking in isolation from the surroundings.

experiential learning since it involves, and is more involved than, other forms of learning.

As an illustration of experiential learning (and of a system delimited by convenience in accordance with Figure 1) that we will subsequently refer to in our discussion, imagine yourself (observer/learner) watching an artist singing on stage. Your experience is primarily affected by the singer (OL), and to certain extents by the orchestra playing the music (learning agents) and the ambiance of the theater arena (mainly the stage and auditorium or seating area). Other factors, like the audience, may also affect your experience, but we choose to ignore them so that we can make our point with the least details possible. The experience then consists of a number of entities that affect, and/or are affected by, other entities, with each entity playing certain functions(s), and undergoing certain operation(s).

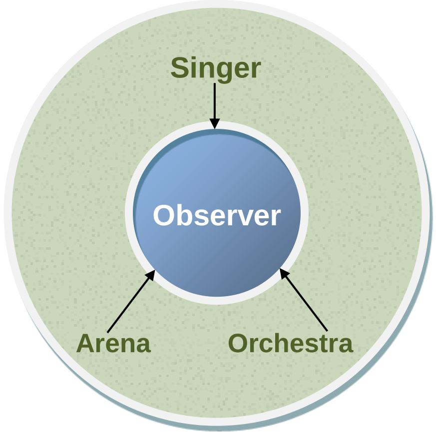

Figure 6. Observer/learner watching a singer on stage.

The one-sided arrows between entities in the environment (singer, orchestra, arena) and the system (observer) indicate that we are only interested in the physical actions (sensory signals) of these entities on the system and not of system on environment. The observer is assumed to be seated, and watching calmly, without any action on the surroundings.

For simplicity purposes, we can define a simple system consisting only of the observer (you) surrounded by an environment including primarily the singer, along with the orchestra and the arena (Fig. 6). We could have defined a compound system consisting of the observer and the singer in an environment including the orchestra and the theater arena. However, in a situation like this, simple systems (consisting of a single element each) usually serve our purposes more efficiently than compound systems.

Your experience is primarily affected by the voice of the singer and the lyrics and music of the song she's singing (auditory signals), as well as by the look of that artist and her movement on stage (visual signals). You may also be affected by similar perceptual signals emanating from different entities in the environment (e.g., stage decor, lighting, sound of musical instruments, as well as somatosensory signals like ambient temperature and smells). Your experience is also significantly affected by all the knowledge you bring along about performing arts, the particular singer, the theatrical piece, and the theater arena, as well as by your emotions, your attitude toward the singer and all other agents, and any somatosensory feelings you might be experiencing then (e.g., pain or any physical discomfort or calmness generated by your emotions). The outcomes of your experience (learning outcomes) "emerge" from the realist-rational "transaction" between system (you) and environment in their "wholeness" (you and your prior knowledge, affects and feelings; all other listed entities and their relevant properties). Those outcomes are not entirely unique to you. They reflect, in certain respects, a pattern shared by the audience watching that same artist as well as by other people around the world with similar theatrical experience. In a nutshell, this experience is a systemic experience that has all the features outlined in the previous section.

Learning outcomes include content and process knowledge, as well as affects, brought about by the end of the experience, and implying memory change (physical change in neural networks and change in the state of mind). An understanding of these outcomes requires an understanding of the dynamic transaction between the learner, as a complex physical and mental system, and her/his environment, and especially of how this person's brain (hard system) and mind (soft system) operate in the process. These two systems are the object of the following two sections respectively.

3. The experiential brain system

Our brain is the store of our memories and the central processor of our perceptions, thoughts, affects, feelings (emotionally generated physical sensations), and actions, and it thus governs all our learning experiences. It is the major part of our nervous system – which has been traditionally and duly called a "system" –, an intricate system that is usually divided into two complex systems, the peripheral nervous system and the central nervous system. The latter includes the spinal cord and the brain. The brain is a complex system composed of billions of neurons grouped and interconnected in neural *networks*, each of specific structure and function. These networks form neural *patterns*, which allows us to conceive them as finite sets of interconnected brain subsystems (or systems for simplicity) from either a morphological (structural) perspective or a phenomenological perspective (operational with specific outcomes). From a morphological perspective, the brain is usually divided into four systems: the *brainstem*, the *cerebellum*, the *diencephalon*, and the *cerebrum*. Figure 7 provides some details about the four interacting systems that are relevant to our discussion in this paper, and that would help readers like me with limited knowledge about the anatomy of the brain to follow

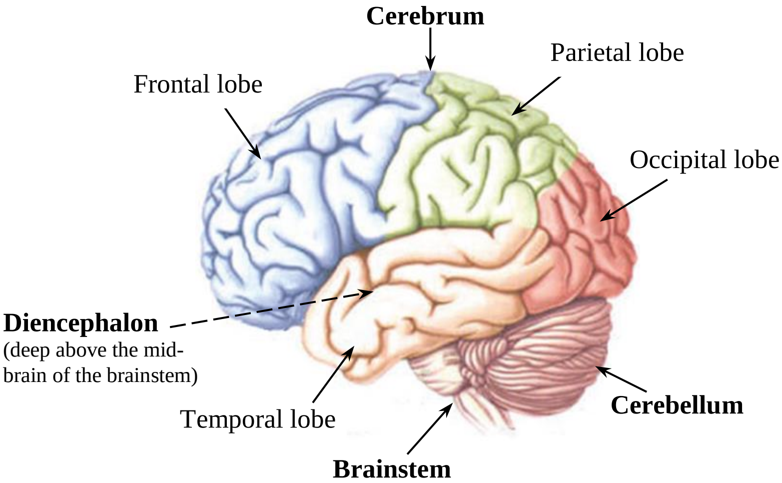

Figure 7. Morphology of the brain (constituent systems in bold) and the four lobes of its cerebral cortex.

The *brainstem* consists of the medulla oblongata, the pons, and the midbrain. It receives somatosensory signals from the skin, muscles, and other parts, and relays sensory and motor signals between the peripheral nervous system and the spinal cord, on the one hand, and the cerebellum and cerebrum on the other. It is also responsible for the coordination of vital and reflexive functions.

The *cerebellum* makes up about 10% of the brain volume but takes in more than half of all its neurons. It modulates movement and is primarily involved in the development of motor skills.

The *diencephalon* consists of: (a) the thalamus which relays various signals to and from the cerebral cortex, and (b) the hypothalamus which modulates autonomic, endocrine, and visceral functions.

The *cerebrum*, or *telencephalon*, is the largest part of the brain (about two thirds of its volume). Its outer portion consists of a thin, heavily wrinkled layer of gray matter called the cerebral cortex. Deep under the cerebral cortex lie three cerebral structures: the basal ganglia, the hippocampus, and the amigdala.
The cerebrum is divided into two hemispheres, the left hemisphere and the right hemisphere, connected by the corpus callosum. The cerebral cortex in each hemisphere is divided into four specialized lobes, each exclusively dedicated to specific function and to sustaining related memory. These are: (a) the frontal lobe that controls thinking, short-term memory and movement; (b) the parietal lobe that interprets somatosensory signals such as taste, touch and temperature, and is concerned with the formation and the outer projection of a body image; (c) the occipital lobe that processes visual signals from the eyes; (e) the temporal lobe that processes auditory signals from the ears, along with sensations such as smell and taste.

Certain parts of the diencephalon and the telencephalon form the *limbic system* that has a prime role in the control of affects and memory. The hypothalamus, the hippocampus and the amigdala are three major constituents of the limbic system that are of prime interest to our discussion.

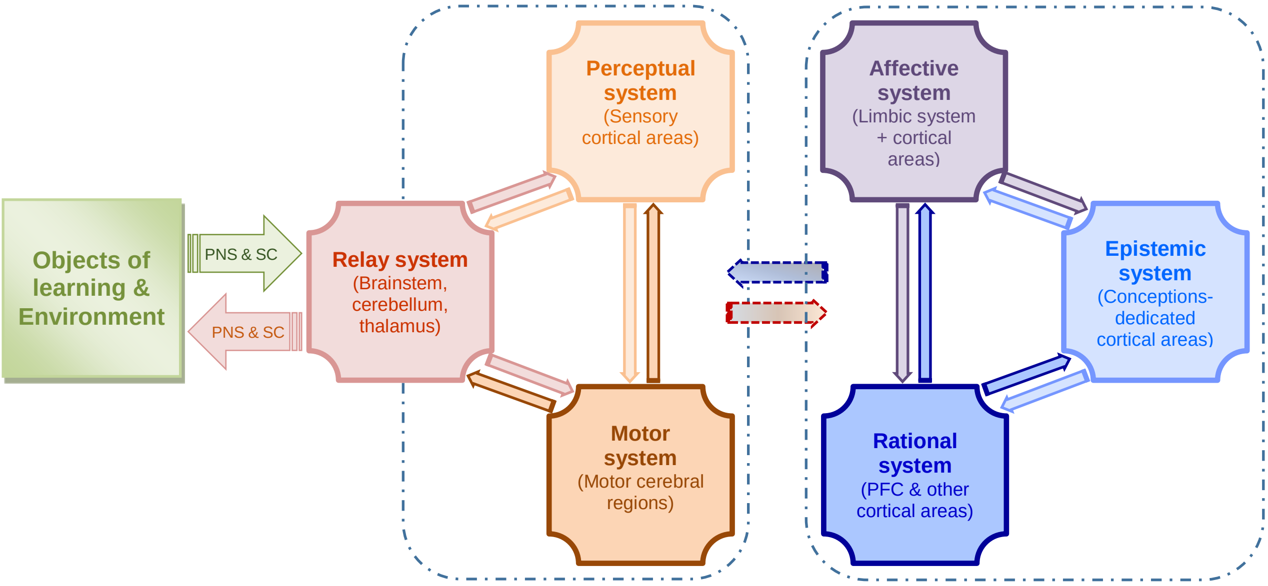

Figure 8. An experiential learning model of the human brain.

The model, like any other model, is a partial representation of the vast cerebral networks and flow of signals across the six brain systems involved in experiential learning, as well as the information exchange between these systems, on the one hand, and objects of learning and the environment on the other, via the peripheral nervous system and the spinal cord (PNS & SC).

the discussion. From a phenomenological perspective, the brain can be divided into a number of systems that may be delineated by convenience as indicated in Figure 1, depending on the mental functions and operations we are interested in. Figure 8 shows a *model* of the brain, i.e., a *conceptual system* that provides a partial representation of how the brain is and works in experiential learning. Box 1 outlines what we will discuss in this section about the dimensions of this system distinguished in the schema of Figure 2, without rigidly structuring our discussion under the titles of these dimensions and in the order of their appearance in the box .

The model represents a learning experience that involves input from concrete objects of learning (OL) and the surrounding environment (Fig. 4). A concrete OL may be an actual physical object or a physical representation of such object (e.g., a physical model, a computer simulation, a photo). The input detected by the senses is sent to the brain for processing, which subsequently induces memory changes in concerned areas of the cerebral cortex (Fig. 7) and implies specific actions by the learner on either or both OL and the surroundings if necessary. The input in the example of watching a singer on stage (Fig. 6), like in typical classroom settings, consists primarily of a mix of visual and auditory signals to which we will come back later in this section. Experiential learning can proceed passively, like in the case of our example, without necessitating any action from the learner on the surroundings. The entire experience,

1. *Framework*. Premises drawn primarily from neuroscience, cognitive psychology, and the philosophy of science.
2. *Scope*. The model represents experiential learning with concrete objects of learning, and serves to describe and explain certain phenomenological aspects of neural networks in the brain regions distinguished in Figure 7 so as to make sense of these objects and bring about specific learning outcomes in memory.
3. *Structure*. The model consists of six interacting cerebral systems shown in Figure 8.
4. *Ecology*. The environment includes objects of learning, and possibly learning agents,with which a learner interacts actively or passively in order to bring experiential learning to its desired ends.
5. *Operation*. Neural signals flow in specific ways across various constituents of the model so as to bring about the desired outcomes.
6. *Outcomes*. Learning outcomes in memory specified in accordance with the taxonomy of Box 2.

Box 1. Schematic dimensions of the experiential brain model of Figure 8.

Epistemic learning outcomes pertain to various types of *conceptions* (concepts, laws, theorems, and other abstract constructs), each of which may be classified in a number of categories (e.g., in science, laws comprise state, composition, interaction, causal, and quantification laws).

Rational learning outcomes pertain to various types of *reasoning skills* (e.g., analytical reasoning, criterial reasoning, relational reasoning, critical reasoning, logical reasoning), each of which may be classified in a number of categories (e.g., analytical reasoning skills comprise surveying, differentiating, identifying regularities, describing, explaining, predicting).

Sensory-motor learning outcomes pertain to various types of perceptual and motor skills, or *dexterities* (e.g., communication dexterities, digital dexterities, manipulative dexterities, artistic dexterities, eco-engagement dexterities), each of which may be classified in a number of categories (e.g., communication dexterities comprise listening, reading, speaking, writing, coordination of multiple representations).

Affective learning outcomes pertain to various types of *affects* (e.g., emotions, motives, interests, dispositions, values), each of which may be classified in a number of categories (e.g., dispositions comprise open-mindedness, risk taking, autonomy, curiosity, creativity).

Learning outcomes along some or all four dimensions may be assembled in clusters of specific functions, e.g., metacognitive controls and competencies. *Metacognitive controls* include reasoning skills and affects that are meant to monitor and regulate our thoughts and actions, and especially memory formation and retrieval. A *competency* is a specific or generic cluster of all four types of learning outcomes. A specific competency helps achieving a specific task like solving a specific problem about a particular system or situation. A generic competency allows the deployment of attained learning outcomes in novel situations and in the development of new learning outcomes (and subsequently new competencies).

Box 2. Taxonomy and assembly of learning outcomes (Halloun, 2013, & in preparation).

from forwarding sensory signals to the brain, to memory change and commanding possible actions on the surroundings, is undertaken by vast neural networks spread across the entire brain.

For convenience purposes, we group these networks into six cerebral systems of six distinct broad functions that serve the purposes of our discussion of experiential learning in this section from mostly a phenomenological perspective. The systems that make up our brain model of Figure 8 are the relay system, the perceptual system, the motor system, the affective system, the rational system, and the epistemic system. These constituent systems are delineated so as to reconcile the actual morphology of the brain and the taxonomy of learning outcomes that we have developed in our work in education. Our taxonomy classifies these outcomes along four multifaceted dimensions outlined in Box 2.

A learning experience may be triggered externally by an input from surrounding objects of learning as indicated in Figure 8, or intrinsically in the absence of any external input (e.g., like in Figure 5, by a process of self-regulation). The model shown in Figure 8 holds in the latter event, with intrinsic triggers substituting OL in the leftmost box and some tweaking to the relay system if no physical interaction takes place with the environment. In such an event, the learning experience is purely *cognitive*; otherwise, and when the learner takes actions in/on the environment, the experience becomes *behavioral* as well. Our discussion thereafter is about experiential learning that involves both cognitive and behavioral outcomes, and that subsequently encompasses para-experiential and non-experiential learning as introduced in the previous section.

Before we go any further with the discussion of our experiential learning model of Figure 8, let us call attention to six important points, four of which pertain to the overall structure of the model, and two others, to the structure and function of each constituent system:

1. The model (conceptual system) is only a *partial* phenomenological model of the intricate brain system. It does not represent all that goes on in the brain during experiential learning,

no matter how simple the learning experience might be. It represents only *primary* aspects that are crucial for the purposes of our discussion.

2. The process beginning and ending with the OL box is not linear. All cerebral systems (relay, perceptual, motor, affective, rational, and epistemic) may constantly interact with each other, directly or indirectly through certain cortical areas or deep cerebral regions, and neural signals may constantly be exchanged back and forth among these systems all during any learning experience. Sometimes, the signal flow may be in one direction but not the other. Interaction between two systems, say A and B, takes place through an exchange of neural signals. These signals are transmitted via neural networks each of which consists of a large number of connected neurons. Because signal propagation is unidirectional across individual neurons (from dendrites to/and the cell body, and then through the axon), signals transmitted from A to B are carried by a neural network that is different from the network carrying signals from B to A. That is what the two opposite arrows between two systems are meant to represent, and sometimes one of these two arrows might be needed but not the other.

3. The clustering together within dashed boxes of three cerebral systems on the left (relay, perceptual, motor) and three others on the right (affective, rational, epistemic) is meant to highlight one critical phenomenological aspect discussed in the following point and not necessarily a morphological reality, nor even a universal phenomenological reality. Any two systems in the two different boxes may always exchange signals as mentioned in the previous point.

4. The clustering of the three cerebral systems on the right is meant to highlight their critical control of the entire learner-OL transaction, beginning with the filtering of perceptual data and letting only some of those data to go through for processing in the brain, and ending with the formation of learning outcomes and the command of specific actions if necessary. This critical control is carried to variable extents by the three systems in question as discussed below, and may, in certain instances, not take place at all. For example, somatosensory signals from the skin and muscles, perceptual input implying reflexive reactions (e.g., turning around in the direction of a sudden sound), and spontaneous actions that involve so-called implicit memory (e.g., handwriting) are entirely and exclusively exchanged between the relay system and the motor system.

5. Specific areas of the cerebral cortex and/or other deep cerebral regions are mentioned below as *primary* constituents of each cerebral system. These constituents may be shared by other systems, and may not be necessarily the only constituents of the system in question. Other parts of the brain may also be involved in the structure and function of any system, but they are not mentioned because their role is beyond the scope of this paper.

6. The distinguished systems are not constrained to the attributed functions. Each of these systems includes neural networks that may serve purposes other than those discussed, and these purposes may even not relate directly to any form of learning. For example, the cerebellum, the thalamus, and the brainstem are primary constituents of the relay system (input and output). The cerebellum, which relays signals to and from the motor cortex, is also a primary contributor to the motor system and is involved in coordinating movement and learning motor skills. The thalamus is the gatekeeper and modulator of most information relayed to the cerebral cortex as well as a prime controller of attention and consciousness. The medulla in the brainstem controls many vital functions like our breath and heart beats.

Let us now outline the structure and function of each constituent system in our model before we discuss how these systems interact and operate in experiential learning. As indicated in Figure 8, once an external input is detected by the senses, appropriate neural signals are sent through the concerned parts of the peripheral nervous system (PNS) to the *relay system* of the brain, directly or through the spinal cord. As just mentioned in the last point above, the relay system consists of neural networks located primarily in the brainstem, cerebellum, and thalamus. It relays somatosensory and other perceptual information, as well as motor information, to concerned parts of the brain, especially in the perceptual and motor systems. It does so not in a passive manner, and not entirely on its own. It actually processes afferent sensory information (neural signals) that goes through it, and induces the affective and rational systems to get involved in focusing attention beforehand on particular sensory data emanating from OL and surroundings.

The *perceptual system* consists of neural networks located primarily in the somatosensory and other perceptual areas of various lobes of the cerebral cortex (Fig. 7). This system processes sensory information filtered through the relay system, generates and sustains in memory our sensations, *perceptions* and *perceptual dexterities*, and determines their outcomes.

The *motor system* consists of neural networks located primarily in the cerebellum and motor areas of the cerebral cortex, as well as in the basal ganglia, brainstem, and thalamus. This system governs our physical actions, generates and sustains our *motor dexterities* (behavioral skills), and determines their outcomes.

The *affective system* consists of neural networks located primarily in the amygdala and hypothalamus that are part of the subcortical limbic system, as well as in certain areas of the prefrontal cortex (PFC). This system generates and sustains our *affects* (motivation, motives, emotions, dispositions, attitudes, interests, beliefs, values, etc.), and significantly influences our feelings, thoughts, and actions, thus the progression and outcomes of any cognitive or behavioral experience.

The *rational system* consists of neural networks located primarily in PFC, and spread across other areas of the cerebral cortex that are involved in our thoughts. This system generates, sustains in memory, and determines the outcomes of, our *reasoning skills*. We call this system rational, and not cognitive, because cognition, i.e., construction and deployment of content and process knowledge, involves not only reasoning skills, but also affects, conceptions, and perceptual and motor dexterities.

The *epistemic system* consists of neural networks located primarily in cortical areas dedicated to particular types of content knowledge. For example, in the case of language, these areas include: (a) the Wernicke's area, located in the temporal lobe of the left hemisphere, and dedicated to auditory comprehension (whence its involvement in perceptual outcomes); (b) the Broca's area, located in the frontal lobe of the left hemisphere, and dedicated to the production of speech (whence its involvement in motor outcomes); (c) the visual word form area, located in the occipital lobe, along with other areas dedicated to shape, and dedicated to the recognition of the shape of written letters; (d) a number of association networks located in the posterior temporo-parietal and occipito-temporal lobes of the left hemisphere, and dedicated to proper associations between phonemes and graphemes, and to matching sounds and prints to meaning. The epistemic system processes content knowledge, generates and sustains related memory, and determines the outcomes of our *conceptions*.

Our model of the experiential brain made up of the six cerebral systems is derived from reliable research in cognitive science and, especially, neuroscience. For decades now, pedagogy has relied, in its cognitive premises and prescriptions, almost exclusively on behavioral sciences and inferences derived in psychology and education from the behavior of learners in specific experiences. Those inferences, as neuroscience has shown lately, have often turned out to be inconsistent with how the human brain actually is and works. They permeated the educational community with pedagogical myths that prevailed for decades, and even centuries now, and that often prevented learners at all levels from achieving meaningful and sustained learning

(Christodoulou, 2013; Holmes, 2016). Technological advances are allowing neuroscientists to actually “observe” what goes on in a learner’s brain during specific experiences, and discern the “real” state of cerebral structures and processes involved in pertinent perceptions, conceptions, thoughts, affects, feelings and actions (Fischer et al., 2007; Kandel, Schwartz, Jessel, Siegelbaum & Hudspeth, 2013). Educators have just begun to catch up with the brain revolution and realize the urgency to transcend the traditional myths and consider a major paradigm shift in education (Campbell, 2011; Dubinsky, Rochrig, & Varmam 2013; Dumont, Instance, & Benavides, 2010; Sousa, 2010).

In the following, we concentrate our discussion on two processes and related metacognitive controls that are most critical for determining how meaningful a learning experience can be, i.e., how well the learner can make sense of and “understand” the objects of learning, and how readily and productively s/he can bring about significant learning outcomes and deploy them in novel situations. The first process is the filtration of sensory information afferent to the brain for conscious processing, and subsequent memory development and possible action. The other and complementary process involves the deconstruction and then the reconstruction of the filtered perceptual data in decisive ways for meaningful learning and memory changes. The course and outcomes of these processes are governed by a number of metacognitive controls the most important of which for us here are attention and regulation, which, in turn, are driven by motivation and other affects. These controls and related affects will also be the object of our discussion hereafter. The discussion of the actual formation of learning outcomes (content and process knowledge) and memory development from a pure mental perspective is left to the following section.

3.1. Multi-stage filtering of afferent sensory information

When a conscious learning experience is triggered externally by sensory information, the peripheral nervous system send detected information, directly or through the spinal cord, to the brainstem or cerebellum (*relay system*) for transfer to concerned cerebral systems (Fig. 8). However, not all input available to our senses is sent to our brain for conscious processing. The afferent sensory information (neural signals reaching the relay system) is filtered at different levels in the brain, before and while it is being processed there. Filtering takes place first in the relay system, and then at a later stage under the affective system, and more consciously and purposefully under the rational system. However, PFC may intervene (with its attentional control system) to focus our senses beforehand on specific sensory data emanating from objects of learning (OL), which helps sharpening our perception and thus our consciousness. Certain voluntary and conscious controls in our affective system, like motives and interests, may also contribute to focusing our attention beforehand on selective cues. The choice of such cues determines the direction in which our thoughts and actions will proceed, and the quality of their outcomes.

Filtering of afferent information begins in the relay system, and more specifically in the activating system of the reticular formation located at the core of the brainstem, and then in the thalamus located between the brainstem and the cerebrum. At this stage, the filtering process is completely automatic and involuntary, and driven by our survival needs and our instinctual emotions. The reticular activating system (RAS), which involuntarily governs our attention and consciousness, allows only a fraction of the signals forwarded to the relay system to proceed through for conscious processing in concerned systems of Figure 8 (only thousands out of the millions of information bits that RAS might receive in any given second are ushered in to the other cerebral systems). For instance, when we look around, light coming from all objects falling in the field of our vision enters our eyes. However, once corresponding neural signals reach RAS, only a fraction of them is allowed through for processing in the visual cortical areas of the perceptual system. This is the fraction we "concentrate on" or "pay attention to", like the word or part of the word you "read" at any particular instant as you go through this text. The remaining signals (background information, including the part of the text that is not being read at a given instant) are blocked out. Sometimes, certain information, including background information, may bypass RAS to be relayed directly to the perceptual and rational systems where it gets unconsciously processed (possibly resulting in motor commands sent back through the relay system to concerned organs). This happens when RAS is overloaded with information, or when we are completely distracted by our thoughts in the rational system, so that we may "look but do not see" or "listen but do not hear". A form of tacit memory is developed as a consequence that may be ultimately "remembered", i.e., accessed and retrieved, and then activated.

For meaningful and durable learning, attention needs to be focused on engaging experiences that bring about emotionally significant outcomes for the individual's development (Zak, 2015). This requires the development of optimal, intuitive and almost automated means for directing attention to input that is significant to the situation we are in, and that positively and coherently engages our perceptual, motor, epistemic, and especially rational systems. Such means need to be induced and sustained by positive affects, and are primarily handled by the rational system, and particularly some of the so-called "executive functions" of PFC discussed last in this section.

Once afferent information is filtered in RAS, the selected information is sent to the perceptual system for processing. The affective and rational systems get then activated to further contribute to input filtering and determine which other constituent systems of the brain will get involved in processing the information that makes it through, and to what end. The most critical constituents of the *affective system* make up a subsidiary affective system that we will thereafter refer to as the "critical (subsidiary) affective system" (CAS). CAS consists of a number of *innate* neural networks that *instinctually* govern what Ekman (1992) and other psychologists call "basic emotions", or what Panksepp (1998, 2006) and other neuroscientists call "core emotions" (Gregory & Kaufeldt, 2015; Panksepp & Biven, 2012). CAS, like RAS, may allow or not affluent information to be processed in concerned cerebral systems. It further determines, to a significant extent, the nature and quality of the cognitive and behavioral outcomes of our thoughts and actions. Some of the CAS networks play a constructive role and allow meaningful learning to proceed, while others take over in a destructive way, unless they are inhibited by PFC, and may prevent any learning from taking place.

The constructive CAS network that is most critical for learning is the one that certain neuroscientists call the seeking/expectancy neural network (Panksepp, 2006; Panksepp & Biven, 2012; Pink, 2009). At the core of this network is the nucleus accumbens, located in the basal forebrain close to the limbic system. It releases dopamine, the neurotransmitter that generates enthusiasm for positive motivation, as well as serotonin, the neurotransmitter that plays a critical role in sustaining or suppressing the positive mood generated by dopamine (Cohen, 2015; Sawada et al., 2015). As such, the network in question "helps mediate our desires, our foraging, and our many positive expectancies about the world", and makes us think and act "in goal-directed ways" (Panksepp, 2006).

The most destructive networks of CAS are those concerned with the negative instinctive emotions of survival, and the cerebral parts of CAS that sustain these emotions are primarily the amygdala and, to a lesser extent, the hypothalamus located in the limbic system. The emotions in question include fear (e.g., of teacher or exam), rage (e.g., because of an incident with classmates or parents), panic (e.g., as a result of missing a question on an exam), and discontent (e.g., because of apathy toward teacher or disenchantment with the school environment). When the amygdala (or hypothalamus) is besieged by such negative emotions, and when it is not positively overridden (or inhibited from releasing its neurotransmitters) by constructive affective areas and/or certain executive functions of the rational system, it may instinctually and unconsciously take a learning experience in unsuitable directions, and it may even prevent learning from taking place altogether.

While filtering is taking place under the control of the affective system, PFC is triggered at two levels to contribute to this process. First, ventromedial areas of PFC get engaged in parallel with the amygdala to circumvent it, and focus on certain RAS filtered signals so as to ultimately affect cognitive and behavioral decisions and processes. Those PFC areas control our social emotions in the affective system (pertaining, say, to accountability, reward and punishment), and can rationally inhibit the amygdala from taking us into destructive courses or unnecessary instinctive actions. Second, the attentional control system (ACS) that is also part of PFC intervenes: (a) to sustain attention on specific perceptual information out of the already filtered information and determine the outcomes in memory, and/or (b) to redirect our senses to focus beforehand on specific perceptual data in the objects of learning. ACS makes up or contributes to the so-called “central executive” in Baddeley’s working memory model discussed below, where its capacity in sustained attention is thought to be limited to a maximum of four chunks of information (Baddeley, 2012; Baddeley & Hitch, 1974).

PFC has many other critical functions in any learning experience that are worth mentioning at this point. Once information is duly filtered, the hippocampus in the limbic system, which controls memory storage and retrieval in various cerebral systems, triggers pertinent cortical areas in those systems, especially PFC areas that handle, in the *rational system*, the “executive functions” of the brain (also called executive function skills, central executive, and cognitive control functions).

Executive functions are widely conceived as the highest level cognitive abilities of the rational system. However, research has not definitely settled yet what executive functions are all about, and different researchers attribute different functions to PFC in this respect. These functions are said to assume, among others, the coordination, regulation, organization, and execution of our complex thoughts and actions. As such, they allow the brain to adapt to rapidly changing situations; they set, plan for, and pursue long-term goals, and inhibit any distracter or impediment that might get in the way of reaching such goals. These functions embrace, in the literature, conceptual development, meaningful learning, prioritization, planning, turning plans into future action, decision-making, insightful judgment, problem solving, creative production, needs and risk assessment, and the ability to anticipate and deal with challenges. According to Baggetta and Alexander (2016), despite the apparent divergence in the literature, there is a “conceptual convergence” that executive functions make up “a set of cognitive processes that: (1) guides action and behaviors essential to aspects of learning and everyday human performance tasks; (2) contributes to the monitoring or regulation of such tasks; and (3) pertains not only to the cognitive domain, but also socioemotional and behavioral domains of human performance”. As such, PFC significantly controls and determines the development of learning outcomes and the extent of their meaningfulness and sustainability in memory.

3.2. Deconstruction and reconstruction of objects of learning

Afferent sensory signals filtered in the relay system make up a preliminary, partial *perceptual image* of the objects of learning (OL). The image is immediately analyzed in specialized areas of the perceptual system and broken down into an array of discrete and unimodal perceptual information (neural signals). That information is then gradually

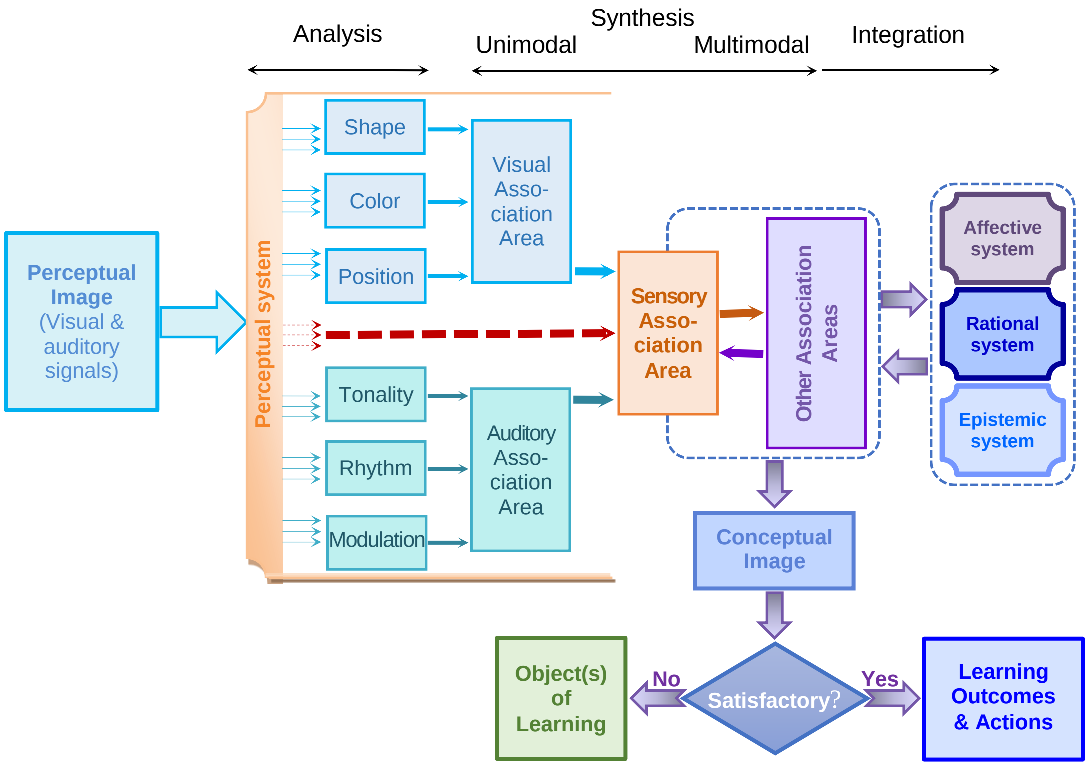

Figure 9. Analysis and synthesis of a filtered sensory input (perceptual image) for the cognitive reconstruction of the object(s) of learning (into a satisfactory conceptual image).

synthesized, first within specialized association areas (called unimodal association areas), then within more complex association areas (called multimodal association areas) located at the interface of various brain systems of Figure 7 (Saper, Iversen & Frackowiak, 2000). Multimodal synthesis takes place under the conscious control of the rational and affective systems and results in a *conceptual image* of OL. This latter image emerges from the perceptual image and the cognitive state of the learner, and involves the adduction of information (neural signals) from memory spread across various cerebral systems of Figure 8. It is gradually constructed so as to help fulfilling the purposes originally set for the learning experience, and allow learning outcomes to be formed in memory and proper actions to be generated by the motor and perceptual systems to this end.

Let us go back to our example of watching a performing artist on stage (Fig. 6) to illustrate this deconstruction and reconstruction of objects of learning (OL). The process, as we shall see next, is often a reiterative process that involves successive generation, analysis and synthesis of perceptual images, and gradual formation of a panoramic conceptual image of OL, i.e., an image formed by successive refinement and superposition of many "shots" taken of OL (Fig. 9).

As you follow the artist on stage, you look at her and listen to her voice. Your eyes detect visual information that is processed in the relay system to tease out the visual constituents of the perceptual image. Those constituents are then channeled to occipital cortical areas of the perceptual system where they are analyzed to form, say, three discrete packages of information pertaining to shape, color, and position or movement of the singer. Similarly, your ears detect auditory information (a mix of acoustic and linguistic data) that is filtered to sort out the auditory constituents of the perceptual image. Those constituents are then channeled to temporal cortical areas of the perceptual system where they are analyzed to form, say from acoustic and non-linguistic perspective, three other discrete packages of information related to tonality, rhythm, and modulation. Similar analysis into unimodal packages takes place for the linguistic and other components of the perceptual image (PI). Such additional analysis is represented by dashed arrows emanating from the perceptual system in Figure 9, and is not further discussed here to illustrate and make our point with the least details possible.

Once the analysis of PI ends, a gradual synthesis of the unimodal information packages begins that culminates in the formation of a conceptual image of the objects of learning. The three visual packages are first sent in parallel along three separate neural pathways to a *unimodal* visual association area where they get integrated in a single visual package of neural signals. Similarly, the three auditory packages are sent in parallel along three separate pathways to a *unimodal* auditory association area where they get integrated in a single auditory package of neural signals. The two integrated unimodal packages (visual and acoustic) are now sent, along with other unimodally integrated packages, to be integrated together in a single package within a *multimodal* sensory association area located in the posterior part of the cerebral cortex, at the interface of the parietal, temporal and occipital lobes. The newly integrated information is projected into other association areas for further processing and integration. The latter synthesis involves adduction of knowledge already in memory (i.e., neural input from various cerebral systems), and is controlled by the three rightmost systems of figures 8 and 9 (affective, rational, epistemic).

The entire process, from perceptual image (PI) formation to multimodal synthesis, is reiterated under the conscious control of the affective and rational systems, especially executive functions and the attentional control system (ACS) in PFC. By the end of a multimodal synthesis course, a conceptual image (CI) is formed of the object of learning (OL, the singer). CI emerges from the synthesized perceptual signals and adducted information from the learner's prior knowledge. Certain executive functions evaluate CI in terms of its suitability to serve the purposes of the learning experience. When the evaluation outcome is not satisfactory – and usually it is not after the first PI-CI cycle –, PFC commands to refocus our senses on specific aspects of OL that help serving those purposes, and the PI-CI cycle is reiterated. Reiteration continues as discussed in the following section until a panoramic CI is formed (by successive refinement and superposition) that satisfactorily helps fulfilling those purposes.

PI faithfully mirrors in specific respects the ontology of OL. In contrast, CI is a holistic, non-positivist, non-gestalt image of that object. It emerges from PI and the cognitive state of the learner. CI is a brain-constructed image of OL formed via the cognitive lenses of the learner. It serves to make sense of OL and the entire learning experience, and is translated within concerned cerebral systems into proper emotions (e.g., pleasure or discontent), thoughts (song interpretation and related inferences), feelings (facial expression, tears to your eyes), and actions (continue or discontinue to watch). Those outcomes induce certain temporary and/or permanent changes in memory in the manner discussed in the following section.

The analysis of the perceptual image into discrete visual and auditory packages in the perceptual system is automatic, unconscious and involuntary, and so is the unimodal synthesis that takes place in the corresponding association areas. Conscious and voluntary cognitive intervention begins with multimodal synthesis as indicated by the rightmost couple of opposite arrows in Figure 9. As mentioned above, the learner then adducts prior knowledge stored in memory for the formation of an appropriate conceptual image that allows meaningful transaction with the object of learning, and emergence of appropriate learning outcomes in memory.

All in all, the multi-cyclic deconstruction and reconstruction of the object(s) of learning that begin with the analysis of PI and end with the formation of a panoramic CI, and that result in learning outcomes of various types (Box 2), proceed as follows in experiential learning:

1. The experience with concrete objects of learning (OL) begins with the formation of a preliminary perceptual image (PI) of OL. The image consists of sensory information (neural signals) that has been selected out of the afferent information received by the relay system.
2. Once PI reaches the perceptual system, it gets automatically analyzed and disintegrated into discrete unimodal constituents that are immediately synthesized afterwards into coherent but unimodal packets which in turn are gradually synthesized into multimodal packets to form a conceptual image (CI) that serves to make sense of the experience at hand and bring about desired learning outcomes.
3. Analysis and synthesis proceed serially and hierarchically in concerned cerebral systems.
4. Filtering of the afferent information to bring about PI is unconscious and involuntary in the relay system, and particularly by RAS. PFC may though consciously and selectively focus attention beforehand on particular aspects of OL that help fulfilling the preset purposes of the learning experience.
5. Analysis of PI in the perceptual system and subsequent unimodal synthesis are also unconscious and involuntary. In contrast, multimodal syntheses and formation of CI are conscious and voluntary, and controlled by the affective and rational systems.
6. CI is evaluated by executive functions in PFC that may induce the PI-CI cycle to get repeatedly reiterated so as to gradually produce a panoramic CI that helps fulfilling the purposes of the learning experience meaningfully.
7. Attention, motivation, and emotions sustained in the relay, affective, and rational systems primarily govern the makeup of PI and CI, along with prior knowledge adducted from memory.
8. Attention focused by PFC is highly critical for multimodal synthesis, i.e., for meaningful reconstruction of PI into CI. Without it, what comes out of the analysis (deconstruction of PI) and unimodal synthesis processes fades out and gets dissipated leaving nothing to synthesize.
9. Executive functions of PFC play a critical role throughout the learning experience, but especially in the formation of CI and ensuing memory storage and actions.
10. The entire experience is a systemic real-rational, or more precisely realist-cognitive synergetic transaction between learner and OL that may be affected by human and physical learning agents and the surrounding ambiance (Fig. 4).
11. The brain of the learner is engaged in its wholeness in the entire experience (Fig. 8), and holistic learning outcomes (LO) emerge out of that experience as a consequence of the realist-cognitive transaction between learner and OL.
12. The deconstruction of OL that actually begins before the formation of PI (through selective attention focus by PFC) is not a simple, positivist analysis or reduction process, and the reconstruction of OL into CI is not a simple synthesis or gestalt process.

4. The systemic mind

Any learning experience involves cognition, i.e., information processing in the brain (reiterative PI-CI cycles) for the construction and deployment in our mental realm of content and process knowledge, along with related emotions and other affects, and subsequent change in memory (i.e., learning). In the previous section, we have outlined how the brain system processes sensory information in experiential learning in order to construct knowledge about physical objects of learning (OL). The outline was carried out mostly from a biological perspective in morphological and, especially, phenomenological respects. In this section, we concentrate on how the human mind operates in the "mental" realm, and more specifically on systemic memory processes involved in the formation of the conceptual image and subsequent learning outcomes. Our discussion follows the schema of Box 1 in the same manner as we did before, with a focus more on conceptual aspects than biological aspects of the conceptual image formation and learning outcomes emerging in memory.

As mentioned above, the conceptual image (CI) emerges from a realist-cognitive transaction between OL and the brain, and more specifically from dialectics between the perceptual image (PI) and knowledge adducted from memory that may pertain to all four dimensions of the taxonomy of Box 2, so as to satisfactorily serve the purposes of the learning experience. Dialectics are regulatory negotiations that take place externally and internally in order to continuously refine PI, and thus insightfully regulate CI, until satisfaction is met. All sorts of dialectics actually take place with CI, and perceptions are subsequently redirected, primarily by PFC, on specific aspects of OL to result in new or refined PI. External dialectics consist of correspondence assessment with OL to establish the validity of CI to represent OL, and may also include commensurability assessment to establish the consistency of CI with related academic knowledge. Internal dialectics consist of coherence and consistency assessment within and between the learner's CI and adducted prior knowledge, and particularly memory patterns (Halloun, 2004/6).

Adducted knowledge may originate in two types of memory, short-term memory and long-term memory. Short-term memory (STM) consists of information temporarily maintained in mind and processed under the control of PFC for the sole purposes for which the information has been retained, and only for as long as these purposes need to be served. STM pertains, for us, to the formation (as process and product) of a panoramic CI in reiterative PI-CI cycles, and may extend a little beyond the conclusion of the reiterative process depending on the need for the image in question and emerging learning outcomes (Fig. 10). In each PI-CI cycle, unimodal synthesis of discrete perceptual information brought about by unimodal analysis of the perceptual image results in data that need to be retained for subsequent multimodal synthesis. The lifetime of synthesized unimodal data in memory (STM) is very short in a given cycle. It may last from a fraction of a second up to a very few seconds. Should the data be needed for subsequent cycles, they would have to last longer in STM depending especially on the complexity of OL and the dialectics with adducted prior knowledge. An entire PI-CI cycle, and

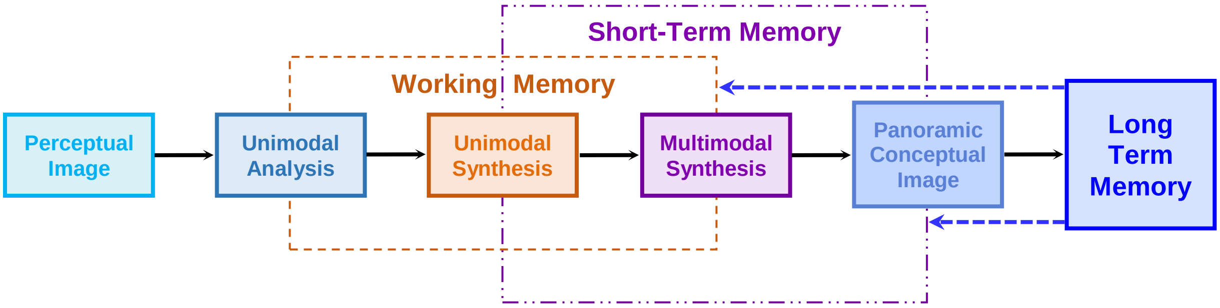

Figure 10. Sequential memory formation (with WM and STM overlap).

some reiterations of it, can be partially represented by any of the “working memory” (WM) models proposed in the literature (e.g., Baddeley, 2012; Baddeley & Hitch, 1974; Cowan, 2014; Pickering, 2006). However, WM is thought to last for a maximum of 30 seconds. The PI-CI cycles may be reiterated for longer than that, and a series of panoramic CIs may be needed to have a comprehensive representation of OL in any particular experience and form meaningful information about the objects of interest. For instance, in the case of our example, watching the singer performing on stage for minutes, and perhaps for hours, requires multiple panoramic CIs, and thus multiple WM episodes to form new knowledge about the singer (learning outcomes), and/or refine prior knowledge about that person and the entire experience at hand. This of course assumes that the WM models were valid for any type of knowledge distinguished in Box 2, and not just for epistemic, and more specifically factual knowledge.

New information emerging at the end of each PI-CI cycle (or WM episode) may thus need to be retained for the entire learning experience, and perhaps a little beyond, even if the learner is interested in temporarily but not permanently retaining such knowledge for any reason (e.g., the itinerary of the show in our example). Reiteration of the cycle in question takes place under the control of PFC that: (a) keeps all processes and outcomes focused on the specified task, (b) retains primary or relevant information emerging at the end of each cycle and deletes secondary or irrelevant information, and (c) ensures that all cycles complement each other in order to form cohesive conceptual images that bring the learning experience to the desired ends. In each cycle, metacognitive controls to which PFC is a major contributor govern all sorts of dialectics mentioned at the beginning of this section in order to regulate the conceptual image constructed in the preceding cycle along all dimensions of the system schema of Figure 2. The regulatory reiteration in question is helicoidal in the sense that appropriate dialectics continue to enhance CI from one cycle to the next until the desired panoramic image is satisfactorily constructed (Fig. 11).

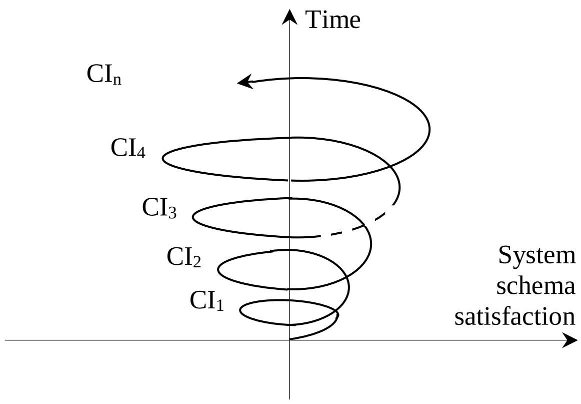

Figure 11. Helicoidal and regulatory reiteration of PI-CI cycles.

When the conceptual image (CI) is of a system object of learning that is an instance of a particular pattern, the image CI_j constructed by the end of a cycle j is developed and/or refined in the following cycle j+1 so as to better meet the system schema of Figure 2, especially the system function and structure, and better reflect the pattern in question. The partially dashed line between CI_3 and CI_4 indicates that a given cycle (or WM episode) may be interrupted for any reason, but PFC would ensure that the information constructed by then is retained in STM, and would eventually bring the task back on track and ensure that it continues from where it got interrupted.

Information emerging at the end of each cycle is retained – and processed – in STM for as long as it is needed, and is subsequently dropped out of memory unless it makes its way to long-term memory. The lifetime of CI / STM about a given OL or learning experience can span from a few seconds or minutes to a few weeks. In formal education, the latter is the case when students have to retain content or process knowledge they are not interested in, and when constructive affective and rational controls are not strong enough to induce such knowledge to be retained for good in long-term memory. Students retain required knowledge only long enough to pass a certain quiz or exam. Once the purpose is served, and the information is no longer needed, it is dropped out of memory altogether (or perhaps inhibited from being consciously remembered and retrieved). That is why, students who are able to do well on a certain quiz or exam are unable to do as well a short while afterwards on the same task.

From a morphological perspective, STM consists of neural networks established under the control of PFC. Each network is made up of a large number of neurons located in a given specialized area of the cerebral cortex (Fig. 7). It is established once concerned neurons exchange appropriate neurotransmitters at the synaptic level so as to properly "encode" the needed information. The strength of the synaptic networking determines the lifetime of the encoded information. Once that information is no longer needed, the network in question gets dissociated, and the information is dropped out of memory. The learner is then said to have accomplished *transient learning*. This is the case of students who retain knowledge only for the purpose of passing exams as mentioned above. Alternatively, the learner accomplishes *sustained learning* when the information is never dropped out, and is retained instead in long-term memory (LTM). This happens when neural networks in which information is encoded: (a) are strengthened enough with synapses getting sufficiently larger and stronger than before with the production of appropriate neurotransmitters, and (b) connected to proper LTM networks under the control of, and through the hippocampus located in the limbic system. Such transformation of STM into LTM also requires that: (a) PFC be constantly involved in monitoring and regulating the entire process, and that (b) motivation and other positive affects be always there to instigate and sustain that process.

According to Lakoff (1987, p. 346), it "*is easier to learn something that is motivated than something that is arbitrary*. It is also easier to *remember* and *use* motivated knowledge than arbitrary knowledge". Our own research has shown that the overwhelming majority of positively motivated students have high achievement in science courses of all levels (Halloun, 2001b; Halloun & Hestenes, 1998). Research also suggests that there is an interplay between students' affects and their conceptual background and understanding. On the one hand, students with positive affects are inclined more toward, and capable of achieving under propitious conditions, meaningful learning than rote learning of course materials. On the other, students who attain certain threshold of conceptual understanding (Décamp & Viennot, 2015), or who perform better in a given situation than they expected (Cohen, 2015), tend to have more positive affects than their counter-peers and to better sustain their drive for meaningful understanding, success, and progress. Moreover, the literature suggests that executive functions and positive dispositions, like grit, tenacity, and perseverance, significantly contribute to sustaining such drive, and that these functions and dispositions can be explicitly nurtured in the classroom with properly challenging activities (Shechtman et al., 2013).

Long-term memory (LTM) consists of content and process knowledge permanently retained in memory, i.e., encoded in stable neural networks that are spread in various cerebral systems, and especially specialized or dedicated areas of the cerebral cortex. Two types of LTM are distinguished in the literature primarily depending on: (a) the relative degree of awareness and consciousness involved in memory formation and retrieval, and (b) which of the rational and motor systems is predominantly involved, i.e., on whether adducted knowledge is predominantly cognitive or behavioral, and whether it involves mostly reasoning skills or motor dexterities. These two LTM types are often called explicit and implicit memory. *Explicit* memory (sometimes called declarative memory) involves conscious and reflective processes (e.g., evaluation and self-regulation), and relies heavily on prior conceptions and reasoning skills (e.g., the memory of facts and events, problem solving skills). *Implicit* memory (non-declarative) involves reflexive rather than reflective processes, and relies heavily on motor or perceptual skills that can be unconsciously developed and deployed (e.g., daily care routines, handwriting, hand drawing of geometric figures). General education is concerned with both implicit and explicit memory, but more with the latter than the former. Furthermore, explicit memory is more involved than implicit memory especially at the level of conscious processing. That is why in the rest of this paper, we concentrate our discussion on explicit memory.

LTM is the resource a learner relies upon for meaningful transaction with objects of learning, whether these objects are physical or conceptual, and whether learning is experiential or not. LTM provides the cognitive lenses through which we see the world, no matter how passive and "objective" our transaction with this world is intentionally meant to be. It always determines what we see and what we hear, even when we encounter something or someone for the very first time in our lives. This is how, for example, we may determine that something is a plant or an animal, even when we have never seen it before. Such categorization is carried out by systemic mapping of entities, properties, and especially relationships in the new experience to existing patterns in memory.

4.1. Patterning

Patterning is crucial to LTM, both at the morphological level of the brain and the conceptual level of the mind. LTM neural networks make up morphological patterns in the brain, and connection and activation of these networks involve patterns of neural signals flow and processing across various brain systems. Similarly, patterns predominate in our conceptual realm, i.e., the conscious part of our mental realm that includes content and process knowledge which we are consciously aware of and that we can communicate to, and negotiate with others. A learning experience can result in sustained learning outcomes only if STM neural networks can be readily integrated with LTM cerebral patterns that relate to the objects of learning (OL), or added without conflict with existing patterns if OL are entirely new and look nothing like any familiar object. Furthermore, in formal education, the more our conceptual patterns are commensurable with expert patterns in a given academic field, the more efficient and productive they are (Adams & Wieman, 2015; Čančula, Planinšič & Etkina, 2015; Chi, Feltovich, & Glaser, 1981; Cragg & Gilmore, 2014; Davidson, 2014; Ericsson & Charness, 1994; Gilmore & Cragg, 2014; Hmelo-Silver & Pfeffer, 2004; Kandel et al., 2013; Koob, 2015; Larkin, McDermott, Simon & Simon, 1980; Masson, Potvin, Riapel & Brault Foisy, 2014; Roberts, Robbins & Weiskrantz, 1998; Simons & Spiers, 2003; Zeineh, Engel, Thompson, & Bookheimer, 2003).

A correspondence appears to exist between cerebral patterns and conceptual patterns at the developmental level. Cerebral patterns favor conceptual patterns. The more we consciously focus on conceptual patterns in developing new knowledge, the better the chance for sustained learning, i.e., for the new knowledge to be encoded in LTM cerebral patterns. This mind-brain correspondence holds irrespective of whether or not there is an ontological isomorphism between the cerebral and conceptual patterns, although it would be strengthened by such isomorphism if it were to exist. By ontological isomorphism we mean a one-to-one structural mapping between the cerebral world and the conceptual realm, a mapping that reaches for some the level of a mind-brain or mind-body monism or unity (a controversial position opposed to dualism that we do not delve in).

Our mind-brain correspondence though entails a sort of *nomic isomorphism* between the conceptual image (CI) formed by the end of multimodal syntheses in experiential learning and a given object of learning (OL), on the one hand, and between that image and LTM conceptual patterns on the other, when CI-related mental patterns already exist in LTM. We are here borrowing Hempel's idea (1965) of nomic isomorphism to refer to a syntactic and functional resemblance between the conceptual image and its real and mental counterparts. Syntactic resemblance is a resemblance between relationships among CI constituents and corresponding relationships: (a) among primary OL constituents that are of interest to the learner, and (b) within related conceptual patterns already stored in the learner's LTM, if any. Functional resemblance is about the purposes that image, object, and patterns are meant to serve, each in its own world.

Meaningful learning requires that CI (and thus the perceptual image to start with) be nomically isomorphic with OL so that the emerging learning outcomes can be reliably and successfully deployed in eventually dealing with situations involving this and similar objects. Sustained learning requires that the image in question be also nomically isomorphic with LTM patterns so that it may be efficiently and permanently integrated with these patterns (or at least that CI be not in conflict with LTM patterns should it be entirely new and relate not to any such patterns). Nomic isomorphism is crucial for making sense of PI, and thus of OL, to begin with. Making sense of any experience depends on a variable mix of perceptual and conceptual LTM patterns. In fact, it depends primarily and overwhelmingly on perceptual LTM patterns at early school age. As we get older at school, and with proper training, we can gradually move to depend more on conceptual patterns than perceptual patterns. The shift to predominantly conceptual patterns becomes possible in adulthood (Shing & Brod, 2016), and the level of expertise, and thus of productivity and creativity in any field is primarily determined by the extent to which such shift is made. Systemic thinking can most effectively and efficiently allow the realization of nomic isomorphism within and between the real world and the mental realm, but especially the transcendence of a perceptual perspective on things in the direction of a conceptual perspective, and thus the move toward expert meaningful and sustained learning.

Systems infuse order in the natural, social and conceptual worlds, and allow patterns and nomic isomorphism between physical and conceptual entities to emerge meaningfully to and within the human mind (Bunge, 1979; Gee, 1978; Gentner & Stevens, 1983; Giere, 1992; Glas, 2002; Harré; 1970; Hesse, 1970; Johanessen, Olaisen, Olsen, 1999; Johnson-Laird, 2006; Lakoff, 1987; Wartofsky, 1968). As noted in the first section, systems are in the middle of the conceptual hierarchy between individual details and the big picture (especially a pattern) in any given situation (Fig. 3). As such, they are the best structured entities to ensure the coherence and efficiency of our corpus of knowledge at large, and to reveal syntactic and functional similarities and correspondence between entities of the same or different natures. When the physical world and the mental realm are thought to consist of interacting systems, patterns readily appear in the structure and behavior of various physical realities, from galaxies down to living organisms and microscopic matter, as well as in the structure of human knowledge, especially academic knowledge that is the object of formal education. As a consequence, it becomes easier for us to conceive the physical world and integrate the conceptual outcomes with existing memory patterns (Halloun, 2001a, 2004/6).

Sustained and meaningful learning favors a systemic mindset, i.e., a mind that consciously thrives to explore the world with systemic cognitive lenses, and that subsequently sets systemic purposes for any learning experience and brings about systemic learning outcomes. As such, any learning experience is explicitly carried out as a transaction between two systems, the object of learning (or a larger system which the object might belong to) and the learner. The outcomes of that transaction are also conceived for the purpose of constructing or consolidating a conceptual system that can readily reveal, and/or be integrated with, specific conceptual patterns.

Such a systemic mindset has the advantage of bringing about the desired learning outcomes in any learning experience efficiently and with the least cognitive demands possible, i.e., with the least processing effort possible in various brain systems (Fig. 8), and especially during multimodal syntheses (Fig. 9). It also has the advantage of optimizing the cognitive efficiency of constructed knowledge, i.e., the efficiency with which it is retrieved from LTM, and the success with which it is deployed in novel situations.

4.2. Systemic provisions for sustainable meaningful learning

The discussion above and a careful analysis of related literature lead us to a number of provisions that significantly contribute to advantageous mental processes in reiterative PI-CI cycles, and thus in STM and LTM. Pertinent works on which we draw include, but are not limited to, those of Anderson (2005), Baddeley (2001), Benfenati (2007), Bohbot, Lerch, Thorndycraft, Iaria & Zijdenbos (2007), Bressler & Menon, (2010), Chun & Turk-Browne (2007), Cragg & Gilmore (2014), Davidson (2014), Diamond (2013), Germine, Duchaine, & Nakayama (2011), Gilmore & Cragg (2014; Gold, Murray, Sekuler, Bennett & Sekuler (2005), Hartshorne & Germine (2015), Hernández, et al. (2002), Kandel et al. (2013), Koob (2015), Leff et al. (2004), Murphy, Nimmo-Smith & Lawrence (2003), Postle, Brush & Nick (2004), Ridderinkhof, van der Wildenberg, Segalowitz, & Carter (2004), Roberts, Robbins & Weiskrantz (1998), Shing & Brod (2016), Simons & Spiers (2003), Sousa (2010), Zeineh, Engel, Thompson, & Bookheimer (2003), Zhang & Luck, (2009). In the following is an outline of the provisions in question that stress the importance of systemic learning for sustainable meaningful outcomes.

1. *Systemic controls*. The affective and rational systems that consciously control any learning experience (Fig. 8 and Fig. 9), and especially CAS and PFC respectively in these two systems, work constructively in tandem so as to keep the entire experience systemically focused, from purpose to outcomes, and especially from perceptual image (PI) to conceptual image (CI), including the adduction of necessary information from the epistemic and other systems.

2. *Lean focused purpose*. Focused and reasonable desired outcomes are clearly set ahead of time for any learning experience so as to avoid distraction and overload at any stage. This is best accomplished with a focus on aspects of objects of learning that would eventually lead to lean perceptual and cognitive images, i.e., images with the minimum primary details possible in both the real world and the mental realms, and free from all sort of noise and redundancy. Such lean images can lead to learning outcomes (LOs) that may be successfully integrated and sustained in LTM with affordable encoding and consolidation efforts.

3. *Perceptual image*. An object of learning (OL) is consciously explored as a system or constituent of a system conveniently delineated (Fig. 1) in accordance with the schema of Figure 2. This helps the relay system, and especially RAS, to focus attention on primary aspects of OL for the formation of the perceptual image (PI) and avoid overload with secondary details that are not pertinent to the experience at hand and that might even prevent primary details from making it through RAS in the first place, given the small fraction of information that RAS normally lets through for processing in the brain.

4. *Conceptual image*. The conceptual image (CI) is consciously constructed as a conceptual system or a constituent of a conceptual system that can be readily integrated with LTM patterns. The ability of the image in question to bring about meaningful and sustainable learning outcomes is primarily determined by how well it is encoded in dedicated cortical areas, and by how extensively it proliferates and how strongly it is consolidated in a variety of such areas.

5. *Encoding*. Encoding of a conceptual image in neural networks begins with the unimodal analysis of the perceptual image and continues through multimodal associations (Fig. 9). Unimodal encoding is localized in specialized or dedicated areas of the perceptual system, and multimodal associations can be spread across different cerebral regions and cortical areas, including specialized cortical areas and association areas. The choice of recruited

areas depends on the ontology of OL and its intrinsic properties, as well as on the epistemology underlying the cognitive lenses via which it is being perceived. The more thorough and the deeper the encoding, the wider it spreads across the brain to engage a variety of dedicated and association areas and involve a multitude of representations of a given entity (OL or part of it) or relationship among entities, the more likely it will result in sustainable learning.

6. *Across-the-board associations and learning outcomes*. A learning experience of any type may engage some or all cerebral systems distinguished in Figure 8 and bring about learning outcomes along some or all of the four dimensions distinguished in Box 2, in both implicit and explicit LTM, even when the purposes of that experience are originally set to focus on one particular dimension. For example, exploration of an OL that is meant to figure out properties as simple as shape and color of such object (epistemic LOs) always involve some reasoning skills (rational LOs), e.g., differential analysis to tease out primary from secondary aspects of these properties, some perceptual and motor dexterities (sensory-motor LOs), e.g., focusing eyesight on particular components of OL and perhaps touching and handling the object in specific ways, and even some emotions about the object in question and the entire experience (affective LOs). A learning experience as simple as the considered exploration would practically involve, though to various extents, dedicated areas in all six cerebral systems and corresponding association areas. The extent to which any learning experience may lead to meaningful and sustainable LOs thus critically depends on how well various neural networks are insightfully engaged and consolidated.

7. *Adduction of prior knowledge and consolidation of distributed networks*. Sustainability of learning outcomes is ensured by the gradual consolidation of CI in LTM. This process that involves the adduction by PFC of appropriate content and process knowledge from LTM, and especially from the rational and epistemic systems, in order to properly transform the raw PI into a meaningful CI, and make it possible for emerging learning outcomes to be eventually inducted in LTM. The consolidation begins in the early stages of STM (WM, if conceived differently from STM as in Fig. 10), i.e., in making sense of the product of unimodal syntheses through proper encoding, and integrating this product in multimodal associations. Rich encoding in neural networks distributed across a variety of cortical areas with ample and strong multimodal associations among new networks and with prior knowledge ensures not only the sustainability of emerging learning outcomes in LTM as mentioned above, but also the cognitive efficiency in ultimately retrieving these outcomes and deploying them successfully in novel situations.

8. *Rehearsal*. The transformation of STM into LTM requires the channeling of CI through the hippocampus (which may take days, even weeks, and is mostly achieved during sleep) and the strengthening of synaptic connections within and among neural networks in which the image has been encoded. The process, especially of strengthening connections, is significantly enhanced with repetitive retrieval of STM outcomes and rehearsal (deployment) in a variety of familiar and novel contexts, and subsequently the proliferation, consolidation and strengthening over time of the connections among concerned neural networks. Knowledge retrieval from STM, accompanied with retrieval of necessary content and process knowledge from LTM, is a dynamic evolutionary process. Knowledge retrieved from both memories undergoes transformation during retrieval and consolidation in ways that determine how meaningful and sustainable learning outcomes will be.

9. *Retrieval mnemonics and contexts*. When prior knowledge needs to be recalled for any reason, PFC specifies and activates necessary mnemonics to determine what knowledge needs to be retrieved and how to retrieve it and use it. Mnemonics are retrieval cues and processes that PFC develops during knowledge construction, and that determine the

cognitive efficiency of the knowledge deployment. Mnemonics are often context related. They are most successfully deployed in the same or similar context in which they have been developed. They cannot be readily deployed in novel contexts without proper rehearsal and correspondence rules that facilitate transfer to those contexts. Mnemonics and rules are most effective when consciously and purposefully constructed in systemic perspectives, and when they concentrate particularly on cues emanating from the scope of a given system to determine where and when the system (or any of its constituents) can be deployed and for what purpose (§ 1, Fig. 2).

10. *Retrieval and memory development.* Any memory activation is a dynamic process that results in memory change (development). Knowledge retrieval (recall) from memory, like knowledge construction, is a conscious constructive process that induces changes in stored knowledge while it is being retrieved. The same is obviously true about putting retrieved memory networks into action (knowledge deployment). Changes in question are limited when retrieval takes place in familiar contexts and with the same mnemonics developed in parallel with memory formation. They become increasingly more significant with the level of novelty in new contexts. However, the cognitive efficiency of retrieval and deployment declines then unless explicit rules and processes are consciously developed for memory proliferation and consolidation, including related mnemonics (knowledge growth and deployment).
11. *Differential memory formation and retrieval*. Retrieving knowledge from memory follows different pathways than encoding the same knowledge in memory and involves cognitive processes that differ from those involved in memory formation (encoding, consolidation and storage). Furthermore, knowledge retrieval is a relatively fast process governed by mnemonics dictated by PFC, whereas knowledge induction in LTM is a long process governed by the hippocampus. The differential processes and controls in memory formation and retrieval can best be conciliated, and cognitive efficiency significantly improved, in systemic contexts with particular attention to the scope in the system schema.
12. *Differential outcomes consolidation and rehearsal*. Content and process knowledge, and different types of each (Box 2), are encoded in different cerebral systems (Fig. 7). Consolidating and sustaining neural networks in which a specific learning outcome (LO) is encoded does not automatically consolidate and sustain related LOs of different types, even when all LOs correspond to the same OL/CI. Due attention paid in a systemic perspective to the consolidation and rehearsal of each LO separately and in relation to other LOs (through multimodal associations) ensures the consistency, coherence, and sustainability in LTM of all concerned LOs.
13. *Insightful regulation and metacognition*. The merits of CI, and especially the efficiency of encoding, consolidation, and subsequent rehearsal, are critically determined by the regulation, under the metacognitive control of the rational system and particularly PFC, of all processes and products from PI to CI. Regulation is most effective when it is carried out in insightful ways that make the correspondence lean and transparent between CI (and PI to start with), on the one hand, and OL and patterns in LTM on the other. Insightful regulation: (a) concentrates on systemic aspects of all entities and processes, (b) inhibits distractive processes, (c) filters out noise in CI coming from secondary and redundant information, (d) tightens up loose and fragmented information in that image, and (e) eliminates any conflict or incommensurability between CI and its real and mental counterparts. Insightful regulation is carried with the learner constantly aware that CI and arising learning outcomes are holistic products that emerge from the transaction between OL and learner. As a consequence, these products may be tainted with anomalies that may lead to permanent misconceptions and/or defective skills and dexterities in LTM if the

regulation is not carried lucidly and critically enough in WM/STM and LTM, and properly monitored and kept on track by concerned metacognitive controls in the rational and affective systems, especially in PFC.

14. *Dynamic sustainability of LTM*. Memory patterns are dynamic. Sustainability is thus not a static state but an evolutionary state whereby memory networks may proliferate in ways that preserve their consolidated core structures and processes. Such a preservation implies that, unlike STM, content and process knowledge sustained in LTM cannot be easily "wiped out" and totally "forgotten". Some research even suggests that sustained LTM knowledge may not be wiped out from memory at all (Masson, Potvin, Riapel, & Brault Foisy, 2014). Should LTM knowledge consist of undesirable misconceptions or wrong or dysfunctional processes, proper inhibitory processes need then to be developed in PFC and the hippocampus to prevent their retrieval and activation.

15. *Brain-mind development*, or nature *vs* nurture impact on cognitive development. Biological development of the brain often determines whether or not a given conception, skill, dexterity, or affect (Box 2) can be encoded and/or processed at a certain age or stage of life in corresponding dedicated parts of our cerebral systems (Fig. 8). For example, PFC does not get fully developed, and particularly fully myelinated, until we are in our early or mid twenties, and even beyond for some people. Thus various sorts of abstract thinking and metacognitive controls that recruit executive functions in PFC cannot be conducted until these functions are brought to maturity, some at early school age and most others subsequently and through various stages of adulthood. This, of course, somewhat rhymes with Piaget's stance on cognitive development that brain biological development is a prerequisite to learning and mind conceptual development. In contrast, there are instances where the opposite stance held by Vygotsky holds that learning is a prerequisite to brain development. Such is the case, for example, with the visual word form area located within the fusiform gyrus of the occipital lobe of the cerebral cortex. This area gets biologically developed as we learn to read, and becomes increasingly specialized with the processing and recognition of written letters and words.

5. Systemic education

Education is a dynamic, deliberate and conscious process that works, through various types of learning, on developing the competence of a given individual or group of individuals in specific respects for specific ends. Education can be formal or informal. Formal education is normally regulated by a given authority in a particular educational system, and provides for learning in a structured environment so as to complete certain curricula mandated by that authority. Informal education is undertaken voluntarily by a given person outside the confinement of any curriculum or authority. Our discussion hereafter pertains strictly to formal education. Nevertheless, it applies, to variable extents, and in virtually all respects, to informal education.

Formal education (or education, for short, thereafter) involves continuous transaction between a given learner, or a community of learners typically forming a given class in a given educational institution, and objects of learning in a structured environment that normally includes human and physical learning agents. Objects of learning include a mix of: (a) physical (live and inert) entities which the learner is supposed to develop content and process knowledge about through experiential or para-experiential learning (§ 2), and (b) conceptual or academic knowledge derived from the paradigms of specific professional communities. Human agents include all people the learner (or community of learners) interacts with, peers, teachers, and parents included. Physical agents include all sorts of resources and facilities at the learner's disposal, including paper and digital references. As such, education is, and must be explicitly carried out as, a systemic process that involves the interaction among many complex systems at the core of which is the most important system of them all: the individual learner (Fig. 4). All other systems are there to facilitate the continuous development and empowerment of the learner for lifelong learning, and for a decent and successful life.

The importance of a systemic worldview on all aspects of our life has led many reformists to call, for decades now, for "systems-level understanding" of various topics taught at different levels of education (Garcia et al., 2014; Goleman & Senge, 2014; Johanessen, Olaisen & Olsen, 1999; Laszlo, 2015; Liu et al., 2015). Such calls have been heeded only recently (Box 3), and some educators have begun integrating successfully "systems thinking" in their teaching (Assaraf & Orion, 2005; Hmelo-Silver, Marathe & Liu, 2007; Rodriguez, 2013; Waters Foundation, 2010). We call for a systemic education that provides for a systemic learning ecology (Fig. 4) that explicitly respects the systemic nature of individual learners, especially of their brain structure (Fig. 8) and operations (Fig. 9 and Fig. 10).

For education to be really systemic, it has to be so in all respects. It has to explicitly and systematically: (a) target students as learning systems, (b) aim at bringing them up with systemic profiles, (c) rely on systemic objects of learning and learning agents, and (d) proceed systemically to realize that aim in a dynamic learning ecology that provides for all people and entities involved in the educational process to change at any time so as meet the actual needs of individual learners.

A learner, as discussed before, is a dynamic complex system whose mind and body are always involved in some form of learning especially experiential learning (Fig. 4). The learner's mental and physical parts and properties, and the way they relate to, and affect, each other internally and in relation to the learner's environment, determine the outcomes of any learning experience. In experiential learning, all parts of the peripheral and central nervous systems get engaged in the experience in the manner shown in Figure 8, along with the senses and other body parts. The latter include, but are not limited to those parts that help directing the senses to detect incoming signals (e.g., turning the head to look at something). Latest research in neuroscience shows that movement of the entire body, including walking and exercising during or between class periods, facilitates sustained learning, and promotes cognitive development especially in elementary grades (Jensen, 2005; Kiefer & Trumpp, 2013; Kubesch et al., 2009;

Daniel Goleman, the author of Emotional Intelligence (Goleman, 1995) and an ardent proponent of social and emotional learning, or SEL, acknowledged recently that "we feel SEL offers only part of what students need to be well prepared for life. In today's world of work and global citizenship, young people also need to comprehend the complexity of the problems they will face. Parallel to the development of SEL, for the past 20 years, innovative teachers have been working to introduce systems thinking into pre-K-12 schools to build a third intelligence—systems intelligence. Systems thinking, which has been a hot topic in the business world for years, has been shown to increase student motivation by engaging learners in issues of genuine concern to them, like the causes of conflict, whether among cliques in school or between warring nations... In math and science, for example, systems-based pedagogy and curriculum encourage the intuitive understanding that is often lost when students learn only facts or technical manipulations without understanding the larger processes at work. We all know that memorizing the technical terms for the elements of a cell in biology is much less engaging than learning how a cell functions as it processes nutrients, expels waste, and maintains its integrity in the face of chemicals that threaten it. The same is true for manipulating equations in algebra or calculus without knowing how the real-life engineering or natural systems these equations describe actually operate... Without clear and thoughtful goals, our education system is adrift, and it becomes more difficult to motivate engaged learners and attract and retain talented teachers. We believe understanding oneself, others, and the larger systems within which we all live, offers a real step toward this much-needed consensus."

Box 3. "Educating for the bigger picture" (Goleman & Senge, 2014).

Osgood-Campbell, 2015; Sousa, 2010). Embodied cognition theory “assumes that cognition is essentially carried out in the sensory and motor brain systems” in concert with related senses and body parts, and that even all sorts of abstract concepts from numbers to affects, feelings, and social concepts like desire, pity, justice, freedom, are “embodied in perception and action” (Kiefer & Trumpp, 2013). Education has thus to explicitly attend to the needs of the entire body, but especially to cognitive and developmental needs that explicitly help optimizing the brain structure and operations discussed in section 3, and the systemic mindset discussed in section 4.

As mentioned in Section 1, research in cognitive psychology reveals that accomplished professionals are distinguished from other people especially in their systemic ways of constructing, organizing, and deploying their knowledge. Systemic education brings about learners with systemic profiles that embody professionals’ patterns of success in modern life. Such profiles would pertain to citizens of progressive mindset, productive habits, profound knowledge, and principled affects (4P Profiles), as outlined in Box 4. A 4P profile would be translated in the program of study pertaining to any particular discipline or subject matter into learning outcomes spreading across all four dimensions of our taxonomy (Box 2), and covering as well overall metacognitive and regulatory functions that are indispensable to keep any learning experience focused on task, and to bring it to the desired ends.

Development of systemic profiles in meaningful and constructive ways requires systemic objects of learning and learning agents. Objects of learning consist, as mentioned above, of a mix of physical and abstract entities, academic knowledge included, which a learner is supposed to learn about, and which curricula typically stipulate in their programs of study. Systemic programs of study are explicitly conceived around well-defined systems that allow students to efficiently grasp the big picture in a given discipline, along with pertinent details, in a middle-out approach (Fig. 3). To this end, every item in a program of study is explicitly conceived for the purpose of constructing and/or deploying a specific system in accordance with the schema of Figure 2. Furthermore, every system is conceived lean enough to bring learners efficiently to the target, and ready enough to lend itself to the integration with some other systems within the same and other disciplines.

For decades now, many a researcher has been showing that students often complete their education at any level with fragmented, compartmentalized, and transient knowledge, and many

A systemic person is a well-rounded citizen empowered with a profile for lifelong learning and success in life that incorporates the following four major traits:

Progressive mind, i.e., an overall dynamic mindset with a clear vision, insight and foresight, and an inspirational drive for continuous self-regulation, improvement and growth, and determination to heed and constructively meet various needs and challenges of life at the personal, collective and broad ecological levels.

Productive habits, i.e., generic and efficient cognitive and behavioral habits that are systematically, creatively, and constructively deployed in familiar and novel situations conceived from systemic perspectives, and that are constantly evaluated, refined, and expanded for continuous profile evolution.

Profound knowledge, i.e., a coherent and efficient corpus of knowledge about the field of expertise that is built around a limited number of generic and lean systems and patterns that clearly reveal connections of interest within this field and with other fields, and that readily lend themselves to the systematic and productive development of new knowledge within and outside any field of interest.

Principled affects, i.e., positive affects that are underlined by a widely and duly acclaimed value system, and that are intuitively enacted for constructive ends in all thoughts and actions, whether concerned with one-self, others, or the physical world around us.

Box 4. 4P profiles.
Reproduced from: www.halloun.net & www.hinstitute.org.

an educator has been calling in vain for lean curricula in order to bring about meaningful and sustained learning. The latter unheeded call, often summed up in the 19th century proverbial phrase “less is more”, is nicely expressed in a *Science* editorial by Bruce Alberts (2012), excerpts of which are given in Box 5. Knowledge fragmentation can best be resolved in systemic programs of study, and knowledge compartmentalization can best be avoided when such programs are cross-disciplinary. Cross-disciplinarity is achieved when at least some systems in a given program are constructed with constituents coming from traditionally different disciplines and are deployable in a variety of such disciplines, so as to bring coherence and consistency within and among disciplines, and facilitate transfer across disciplines and to everyday life.

Efficient profile development requires that individual learners interact systemically with all objects of learning and learning agents. As such, systemic curricula explicitly provide for learners to consciously conceive themselves and every person and entity they interact with as dynamic systems, and to take full advantage of systems in their details and their wholeness, and of holistic transactions among them all. Most importantly, any transaction between a learner and any other person and object is open to change and regulation in every respect, from framework to outcomes in the six dimensions of the system schema (Fig. 2). This, of course, requires that the learner have a voice in the process, and that this voice be heard. As such, learner and environment make up a dynamic learning ecology (Fig. 4) in which they constantly interact and cause changes in each other.

All in all, formal education is meant to empower students for lifelong learning, and decency and success, even excellence, in various aspects of life, and not merely to prepare them for taking exams. Such a purpose is best achieved through systemic education that brings about graduates with systemic profiles, i.e., sustainable, constantly evolving profiles that combine in particular progressive mindsets, profound knowledge, productive habits, and principled affects (4P Profile). A systemic profile is defined and developed in the context of systemic curricula that are put together, and are continuously refined, according to the systemic schema of Figure 2. Systemic curricula mandate, under systemic pedagogical frameworks, systemic programs of study, and provide for meaningful and insightful coverage of these programs in a dynamic learning ecology that relies on authentic assessment and, to the extent that is possible, on experiential activities. Systemic Cognition and Education (SCE) is a pedagogical framework we are currently working on to serve these ends. In the following is an outline of SCE presented in the form of a template that may serve for the formulation of any framework for the design and deployment of systemic curricula that explicitly and purposely work on nurturing student systemic brains and minds.

“Research shows that the most meaningful learning takes place when students are challenged to address an issue in depth, which can only be done for a relatively small number of topics in any school year. But the traditional process of setting standards tends to promote a superficial “comprehensive coverage” of a field, whether it be biology or history, leaving little room for in-depth learning. The curricula and textbooks that result are skin-deep and severely flawed... At all levels of schooling, we need to replace the current “comprehensive” overviews of subjects with a series of in-depth explorations. To do so, we will need to abandon the one-size-fits-all textbooks used in schools in favor of a large set of much shorter curriculum units, each designed to facilitate the active exploration of one important topic in depth for a month or so. Importantly, the teachers in each school district should be empowered to cover only a fraction of the topics available for their grade level. Rather than attempt to cover an entire subject such as biology, an impossible task, the goal of each unit should be to challenge students to explore one narrow topic deeply”.

Box 5. “Failure of skin-deep learning” (Alberts, 2012).

6. Systemic Cognition and Education: Toward a systemic MBE-based pedagogical framework

A pedagogical framework is a conceptual system that governs the design and deployment of particular curricula in formal education, and that may be defined in accordance with our system schema (Fig. 2) as follows:

1. *Foundations* (rather than "Framework"). Premises derived from reliable findings in pertinent research about: (a) human biological and mental development, (b) paradigms of related academic fields, and especially corresponding epistemology, and (c) successful practices in related professions. Framework foundations also stem from local culture and vision for society and various production sectors.
2. *Scope*. Design and deployment of a specific curriculum or, ideally, a set of curricula which the same students may follow concurrently or at different times in their lives in order to gradually develop a given profile.
3. *Structure*. Cognitive tenets and principles for the design and management of curriculum materials in an appropriate learning ecology.
4. *Ecology*. School environment in relation to the local community and overall educational system.
5. *Operations*. Rules of engagement with appropriate practice protocols and other guides for optimizing the management and outcomes of the learning ecology within the broad educational system.
6. *Outcomes*. Profile translated into appropriate learning outcomes for specific and/or cross-disciplinary fields at particular school age/level.

In the following, we concentrate our discussion on the premises of a pedagogical framework that are directly linked to the systemic perspective on MBE, the main object of this paper. These premises pertain to framework structure and entailed operations. They include cognitive tenets, pedagogical principles, and operational rules that must be respected in devising and implementing every component of the governed curriculum or curricula, from programs of study to means and methods of learning, instruction, assessment, and evaluation. The premises in question, and particularly tenets and principles, are first outlined in a generic form, and then as they relate to Systemic Cognition and Education (SCE), a generic pedagogical framework for student and teacher education still in the making as this article is being prepared.

6.1. Tenets

Tenets are universal statements of axiomatic nature that lay down the common foundations for all other premises and practices, at all educational levels. They are mostly of cognitive nature, and govern profile definition and development, and thus the specification of realistic outcomes anticipated at specific school ages, along with corresponding programs of study and various other curriculum materials. Among others, tenets stipulate the following:

1. *Learning potentials and human development*: What a learner *can* do, from cognitive and behavioral perspectives, given biological development of certain brain regions and body parts, and what s/he *should* do to promote biological and functional development of these and other cerebral and bodily components.

2. *Patterns of success*: What cognitive and behavioral patterns of accomplished professionals can learners emulate and embody in their profiles.
3. *Meaningful and sustainable learning*: What constitutes meaningful and sustainable learning and what cognitive processes consciously promote such learning in long-term memory.
4. *Metacognitive controls*: What affects and reasoning skills sustain purposeful attention and ensure insightful regulation and constructive processes and outcomes, and what cognitive incentives promote the development of such controls.
5. *Learning ecology*: What profile human agents should have, what conditions physical agents and surroundings should satisfy, and what should govern learners' interaction with them all, in order to optimize learners' profile development.
6. *Measurement*: What conceptual and physical processes and outcomes can reliably ascertain the actual state of learners' mind and brain.

Our position in the above respects can be partially summed up in the following points that are taken into consideration in the formulation of SCE tenets:

1. The mind and brain of any person are in continuous evolution governed by intrinsic and external factors and induced intrinsically through self-regulation or provoked externally through interaction with other people and the physical world.
2. There is an interplay between brain and mind development such that the more we consciously and purposefully learn, the better our brain gets wired (and the "smarter" we get), though the natural potentials of STM (WM included) and LTM may impose certain limits on the thoughts and actions that any learner is capable of at a specific school age.
3. Sustainable learning in LTM gradually gets decontextualized, from early and primary school ages where learners rely more on perceptual information to consolidate their memory, to secondary and even tertiary education where learners become more and more capable of relying on their own conceptual realm.
4. Meaningful and sustainable learning requires long-time rehearsal of new knowledge in familiar and novel situations that are challenging enough to motivate but not discourage learning.
5. Knowledge construction (encoding, consolidation, storage) and deployment (retrieval and rehearsal) engage distinct neural pathways and cognitive controls, and thus impose different cognitive demands and require different cognitive strategies.
6. Different types of learning outcomes are encoded in different parts of the brain, and require different construction (and deployment) strategies even when they pertain to the same object of learning.
7. Coherent and lean organization reduces the cognitive load in encoding and consolidating new knowledge in STM, and improves the likelihood of subsequently storing it in LTM, and eventually of successfully retrieving it with appropriate mnemonics for deployment in new situations. Systems provide in this respect the optimal conscious organization schemes.
8. Learning outcomes brought about in experiential learning emerge from holistic processes that involve realist-cognitive transaction between objects of learning (OL) in their details and wholeness and learners' own bodies and brains, especially their perceptions, conceptions, and thoughts.

9. Learner-OL transaction is most effective and efficient when consciously conceived for systemic purposes, and governed by systemically driven and focused, insightful, and constructive metacognitive controls.
10. Transaction with an object of learning involves reiterative cycles for the cognitive deconstruction and reconstruction of the object. Each cycle begins with the formation of a partial perceptual image of the object and ends with the formation of a corresponding conceptual image or a refinement of such image when already in STM. For cognitive efficiency purposes, learners should focus their attention on primary details that would make up a lean conceptual image of that object by correspondence to corresponding patterns in the real world and in the learner's prior knowledge in LTM.
11. There are universal patterns in humans' mental realm, just like in the physical world. Mental patterns that are most meaningful for success and excellence in modern life are those reflected in the 4P profiles of accomplished experts in different professional communities.
12. The profile of an ordinary person evolves meaningfully and efficiently when it recapitulates the historical development of academic paradigms and the profile evolution of accomplished experts, and when it becomes gradually commensurable with modern paradigms and expert profiles in insightful and experiential ways.
13. The ontology of a person's mind and brain can be neither directly nor exhaustively measured in classroom settings. It can only be indirectly and partially ascertained through the person's conceptions, reasoning skills, dexterities, and dispositions revealed in appropriate learning/assessment tasks.
14. Human learning agents, and especially teachers, are critical agents of profile change and not conveyors of canned academic knowledge.

6.2. Principles

Pedagogical principles are stipulations emanating from the tenets and corroborated by related research especially in educational cognition and psychology. They specify viable (valid, reliable, effective) learning processes that contribute to meaningful profile development under a variety of educational settings, and set the design of the appropriate learning ecology (i.e., its structure, as opposed to respective operations mandated by corresponding rules). Among others, pedagogical principles stipulate the following:

1. *Learning habits*: What learning habits need to be developed for lifelong learning and gradual development of a target profile (4P profile in SCE) in relation to specific academic fields.
2. *Evolution tracks*: What paths can learners follow in order to gradually and successfully develop the desired profile.
3. *Programs of study*: What taxonomy of learning outcomes helps best translate the profile into learning outcomes that can be attained at specific age and points of instruction, and what sort of programs of study can coherently bring together the specified outcomes.
4. *Teaching schemes*: What learning activities can best allow individual students develop the desired learning habits and evolve toward the target profile, and what instructional practices are most suitable to these ends.
5. *Learning ecology setup*: What settings (facilities and resources included) need to be in place (within and outside the school), and what criteria these settings need to satisfy

separately and in putting them together at the disposal of learners working individually and collectively.

6. *Authentic assessment*: What schemes are needed in order to make assessment an integral part of learning and instruction, and, to this end, viably ascertain the extent to which individual learners have attained specific learning outcomes at specific points of instruction, and evolved along the desired tracks.
7. *Evaluation and regulation*: What measures need to be taken to evaluate the feasibility of various aspects of the curriculum (from programs of study to teaching practices) in bringing about the desired outcomes, and subsequently to reinforce effective aspects and fix deficient aspects.
8. *Axiology*: What measures need to be taken in order to ensure that all products and processes respect specific values and ethics, and resonate well with cultural norms and justified individual and collective aspirations.

Our position in the above respects can be partially summed up in the following points that are taken into consideration in the formulation of SCE principles:

1. In order to develop dynamic 4P profiles that can be readily adapted to continuously changing needs of our modern life, students should develop systemic learning habits that are consciously driven for the exploration of universal patterns with systemic lenses and the construction and deployment of representative conceptual and physical systems.
2. For effective profile evolution, and meaningful and sustainable learning, students of all age groups should be guided to become consciously aware of the potentials and flaws in their own profiles, transcend their naïve and obstructive traits, and insightfully regulate their defective skills, dexterities, and conceptions.
3. For curricula to be effective, they should not come in one-size fits all. They should be flexible enough to account for cognitive and behavioral differences among learners of the same age group, and cater for the same learner to the distinctive cognitive needs imposed by different dedicated cerebral parts where learning outcomes of different types are encoded.
4. Formulation of a program of study, design of the appropriate learning ecology, and the choice of all curriculum materials, should respect cerebral and mental potentials of individual learners at specific age and points of instruction and not impose cognitive loads that are beyond these learners' potentials.
5. Programs of study should come with, and promote, a universal schema for the organization of all sorts of knowledge in the form and the context of systems in order to foster meaningful and sustainable learning with the least cognitive load possible.
6. Programs of study should come explicitly in middle-out designs around lean discipline-specific and cross-disciplinary systems that reveal particular patterns in the real world and/or in the conceptual realm of academic paradigms.
7. No conception should be included in a program of study solely for its own sake, but more importantly for the purpose of constructing and deploying a particular system or set of systems.
8. A cross-disciplinary system should have a structure that brings together conceptions from different disciplines, and is constructed and deployed in tasks requiring cross-disciplinary competencies, i.e., clusters of learning outcomes pertaining to specific and generic

conceptions, skills, and dexterities in these disciplines, and across-the-board affects and metacognitive controls.

9. Programs of study should systematically translate the target profile into learning outcomes corresponding to each system or set of systems in the program, in accordance with a well-defined taxonomy of conceptions, reasoning skills, dexterities, and affects, and follow an outcomes' progression within and among systems that matches the normal cerebral, mental, and bodily development of humans during school years.
10. Learning and instructional strategies devised for the construction of specific learning outcomes should be different from those devised for the deployment of those same outcomes, and different strategies should be in place for different types of learning outcomes pertaining to the same type of objects of learning (same system or pattern).
11. Learners should be made consciously aware of the cognitive processes and metacognitive controls involved in the development of new knowledge, and particularly of the PI-CI cycles that bring about desired learning outcomes.
12. Learners should become aware that, because of perceptual and cognitive limitations, conceptual images they develop of objects of learning are prone to errors, and that these images and related knowledge they hold in memory need to be constantly and consciously evaluated and insightfully regulated by correspondence to the real world and the conceptual realm of academic paradigms.
13. For effective and efficient insightful regulation, learning strategies should be developed that recapitulate the history of human evolution and development of academic paradigms, especially with regard to the emergence of erroneous ideas and their successful regulation.
14. For effective and efficient learning, learners should be helped to:
    a) become consciously aware of the limited capacity and span of attention in STM (or WM) in experiential learning;
    b) engage in experiential learning not only hands-on, but most importantly minds-on with systemic metacognitive controls;
    c) develop constructive metacognitive controls that keep their attention focused with a systemic perspective on primary aspects of any object of learning that help bringing about a lean perceptual image of that object;
    d) deeply encode the reconstructed perceptual image (following unimodal analysis and synthesis) in well-coordinated multiple representations in various cortical areas.
15. For meaningful and sustainable learning, learners should be helped to consciously:
    a) develop a rich, but lean and coherent panoramic conceptual image of any object of learning that involves, to the extent that is possible, representations from a variety of academic fields;
    b) conceive that image as a conceptual system that partially represents the object in question;
    c) consolidate that image with prior knowledge in LTM, and insightfully regulate any possible inconsistency with and within that knowledge;
    d) develop desired learning outcomes in a variety of contexts involving the same, similar, and different learning objects;
    e) develop appropriate mnemonics that would subsequently allow the efficient and successful deployment of these outcomes in any novel situation;

   f) develop appropriate rules of correspondence that would subsequently facilitate the transfer of any knowledge developed in a particular academic field to other fields.

16. For meaningful and sustainable learning to be possible to achieve, learners should be:
    a) convinced of the conceptual and practical need for, and merits of, what they are required to learn;
    b) engaged in the design of necessary learning tasks so that they assume ownership of these tasks, and be intrinsically motivated to carry them out with passion, enthusiasm, and perseverance, and bring them to constructive and fruitful ends.
17. Learning and instruction should rely on a variety of authentic assessment tasks that allow assessment "of" learning, "for" learning, and "as" learning.
    a) Authentic assessment "of" learning is meant to reliably ascertain, in the context of a given system or set of systems, the extent to which individual students have:
        i. achieved particular learning outcomes and met the expectations set in the target profile at specific points of instruction;
        ii. adequately followed anticipated progress or evolution paths throughout the course of instruction.
    b) Authentic assessments "for" learning is meant to:
        i. allow students explicitly develop their metacognitive controls and insightfully regulate their own profiles;
        ii. allow teachers track and regulate the evolution of individual students' profiles along the desired paths in efficient and meaningful ways;
        iii. evaluate and efficiently regulate instructional means and practices, and the entire learning ecology;
        iv. contribute to the refinement/reform of the curriculum and the entire educational system.
    c) Authentic assessment "as" learning considers every assessment task a learning task whereby learners do not simply retrieve ascertained content and process knowledge from memory and deploy it exactly as it used to be stored there, but they actually regulate and change retrieved knowledge in the process of adapting it to the task at hand.
18. Curricula should be implemented by systemic teachers who are trained to act as critical agents of systemic profile development and not as conveyors of curriculum materials, and who, to this end:
    a) come with reasonable expectations about what their students can do at any given point of instruction, and what they can do to help students attain desired learning outcomes;
    b) systematically scaffold academic knowledge, preferably through experiential learning activities, using systemic schemes (operational plans and procedures) and schemata (structural templates like the system schema of Figure 2) that resonate well with the morphological and phenomenological patterns of the brain;
    c) carry out their mission flexibly, and adapt various curricular aspects to individual students' needs, from programs of study to the means and methods of learning, instruction, and assessment.

6.3. Rules

Operational rules are procedural statements or pedagogical guidelines that specify how various operations need to be carried out by learners and agents within the learning ecology, and what physical and operational conditions need to be satisfied by various aspects of a curriculum, for efficient profile development in accordance with the stipulated tenets and principles. These rules should come with prescriptive protocols that provide explicit instructions on learner transactions with objects of learning and learner-agent interactions. They should also come with specification criteria or standards and corresponding indicators, design templates, and management rubrics for all physical settings in and around the learning ecology, from course resources, classroom layout, and school facilities and services, to school environment and the educational system at large.

In the following, we provide a non-exhaustive list of curriculum aspects for which operational rules and necessary protocols and/or other guides need to be formulated, without going into the details of our position regarding these matters, which is far beyond the scope of this paper. We just mention here that, for optimal results, rules and guides need to be formulated in a systemic perspective whereby every entity, whether human or not, is conceived as a system or constituent of a system which, in turn, may be part of a more complex system. These systems may go in scale from a given classroom in a given school to a national educational system, and they all operate for a common broad outcome: bringing up students with suitable 4P profiles. Proper structure and operation of all these systems require operational rules and guides that cover among others the following aspects:

1. *Educational system*:
    a) How the entire educational system should be structured and governed.
    b) What value system should govern all actors and practices.
    c) What monitoring and support systems need to be in place for various human agents, and how these systems should be operated and constantly evaluated.
    d) How the entire system should be constantly evaluated and refined.
2. *Cross-curricular convergence*:
    a) How to bring coherently together various curricula followed by the same students during a given school period (typically a given cycle).
    b) How to make curricula of different levels consistently follow from each other under the same tenets and principles in the direction of bringing about graduates with 4P profiles.
3. *Schools and their communities*:
    a) How schools should be designed and governed.
    b) What facilities, services, and resources they should provide, and following which standards/criteria.
    c) What leverage schools have in adapting various aspects of a curriculum to the actual needs and aspirations of their students and communities, and how they should go about doing that.
    d) How they should interact with various sectors in their communities, and what sort of partnerships they should forge with particular educational and non-educational institutions.
4. *Learning management*:
    a) How lessons should be planned, learning activities designed, and all flexibly implemented to cater to actual student potentials and needs.

b) How various types of assessment should de designed and implemented.
c) What physical settings, and especially technological means, are necessary to each task, and how they should be managed.
d) How leaners should interact with each other and with teachers, and what communication, exchange, and feedback channels should be maintained among them.
e) How should learning and instruction be evaluated and results extrapolated.
f) How students and teachers should interact with various other stakeholders.

5. *Professionalism and accountability*:
   a) How teachers and various other human agents should behave and continuously enhance their practices.
   b) How they should be engaged in appropriate professional organizations, how they should contribute to educational research and development, and what incentives they should be given to these ends.
   c) How their actions should be monitored, evaluated, and duly compensated.
6. *Curriculum refinement*:
   a) How pertinent MBE research findings and classroom practice should be conciliated.
   b) How curriculum deployment should be monitored and evaluated in various schools, and how it should be subsequently refined.

7. Final thoughts

This paper was meant to help reconciling neuroscience, cognitive psychology and education from the perspective of an educator equipped with particular cognitive lenses, and to consequently propose an outline for an MBE-based pedagogical framework. Those lenses emerge from the philosophy of science and comparative novice-expert research, as well as from long years of physics and science education research and practice. Proposed perspective and framework have of course their limitations and perhaps even some flaws. However, they are genuinely meant to contribute to the discussion that has been stirred lately by advances in neuroscience among stakeholders in still disparate academic communities. In particular, they are meant to provide some common grounds on which these stakeholders can coherently exchange their ideas for the good welfare of our students at all educational levels. It is unfortunate that these students are still being brought up under educational systems that did not reap yet any of the MBE fruits, and that these systems are still being driven by educational myths that prevent students from developing the profiles they need for lifelong learning and success in the 21st century.

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