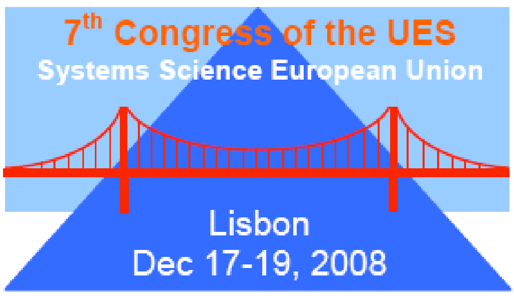
ISBN: 978-972-9059-05-6

the origin/la source : http://www.afscet.asso.fr/resSystemica/Lisboa08/goncalvesTN.pdf
the title/le titre : **Education and cognitive neuroscience: a systemic approach to cognition and learning.**
the author/l'auteur : **GONCALVES Teresa N. R.**
the pages/la pagination : **9 p.**
the year/l'année : **2008**
& the book/la publication: **7th Systems Science European Union Congress Proceedings, Lisboa, Portugal.**

Systems Science European Union
Union Européenne de Systémique
UES
APOCOSIS



Education and cognitive neuroscience: a systemic approach to cognition and learning

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Abstract

The new complexity paradigm – understood as a set of basic assumptions and conceptual tools which dominates thoughts, discourses and theories – challenges educational sciences to reconsider the accepted theories of cognition and learning. I understand the complex systems theory as a conceptual and methodological framework from which to rethink and reformulate the accepted perspectives about development and cognition, offering the possibility to integrate them in a more comprehensive theory. I will argue that the plastic brain model emerging from cognitive neurosciences research is one of the most productive examples of a systemic approach to cognition and learning and must be considered by the educational sciences. The living organisms, as well as the brain, are examples of self-organizing, plastic and complex systems which must be understood as such. Cognitive neuroscience represents a systemic approach to the brain because it is based on the recognition of its plasticity, complexity and the multidimensional character of its development. As such, it integrates the systemic perspective of development in the understanding of the brain as a plastic brain. This model, in contrast with the information processing model or the connectionist model, recognizes the complexity of brain functioning taking into account the genetic, social and learning aspects, opening new possibilities to the understanding and promotion of cognition and learning. The systems theory offers to the study of cognition: a) a systemic approach to development; b) a systemic approach to the brain as the set of cognition, based on the neuronal plasticity model; c) shows the need of a trans-disciplinary approach to cognition and learning which must take into account the complexity and multidimensionality of the learning subject, the learning processes and contexts.

Keywords: complex systems, cognitive neurosciences, cognition, learning, education.

Introduction

The approach to cognition and learning in educational sciences has been dominated, in general, by the three fallowing models of cognition with their different metaphors of the mind: the traditional **developmental psychology approach**, based on the idea of a 'natural' and continuous development process, divided into universal phases or stadiums which would make possible to predict behaviour and to optimize the development trajectories; the **symbolic model** based on the computer as a metaphor of the mind, this model understands the mind as a computer program which manipulates symbols, it is based on the information processing theory and related with artificial intelligence (IA); and finally the **connectionist model** which understands the mind as a formal parallel computation system inspired on the brain functioning and simulated through Artificial Neural Networks (ANN).

These models have coexisted for a long time in the study of cognition, and influenced the educational perspective and practice in what concerns to cognitive intervention and learning processes. We consider that all these models have failed to present a complex, systemic account of cognition and learning. Psychology's development metaphor is centred on regular and linear processes, ignoring change and variability, in this sense, it's a too simplistic perspective once that it doesn't reflect the immense complexity present in real evolutionary change, it fails to give and account of creation and novelty, as such, it represents a teleological and deterministic perspective of human development. The symbolic model is a functionalist model, which understands the mind as the consequence of the peculiar functional organization of the brain and separates it from its physical substrate. In this sense it operates only at a functional level and not at the implementation level, perpetuating the mind-body dualism. Finally, the connectionist model, although representing a more complex approach to cognition and learning, it's still an informatics model which shares with the symbolic model the idea that the subject study of psychology is the mind and that its activity is to process information. Like the symbolic model, this model also remains at a functional level but not at the physic level of implementation. The connectionist models are not brain functioning models, they are theories of mental functioning inspired on the brain (Crespo, 2002).

Although recognizing the contribution of both symbolic and connectionist models to the study of cognition – they contributed to a better understanding of human mind complexity and of the factors interfering in cognition and learning –, the fact is that the learning mechanisms and rules they propose are very far from the real physiologic mechanisms which characterize the human brain learning processes. The human thinker is not a 'logical machine'; therefore, the computational perspective is reductionist. Therefore, we need a more comprehensive and integrative approach to cognition and learning. Furthermore, the new theoretical methodological tendencies developed recently have their origin in an explicit critique of this models of the mind, which, in the light of a new paradigm can be seen as very simplistic and, as such, failing to offer descriptions and explanations which may reflect the manifest complexity of the real evolutionary change.

I argue that the new complexity paradigm – understood as a set of basic assumptions and conceptual tools which dominates thoughts, discourses and theories – challenges educational sciences to reconsider the accepted theories of cognition and learning. The new complex systemic approach to cognition may allow us to conciliate the different existing perspectives in a metatheory [1] of cognition for the following reasons: it represents a more inclusive and comprehensive theory of cognitive development; works with complex, open and non-linear systems; explains variation and novelty (emergency) (Bunge, 2004; Gutiérrez, 2005); refutes the teleological understanding of the systems by understanding them as self-organized [2]; and evidences and makes convergence necessary (trans-disciplinarity) (Bunge, 2004).

Within this perspective I think that the plastic brain model, emerging from cognitive neurosciences, is consistent with this approach. It is an operative and productive model integrated in a systemic approach. This model adds to the evolutionary and systemic perspective of development the systemic perspective of the brain and brain functioning, complements the formalistic views with the implementation physical level, and integrates it in a biological evolutionary perspective accounting for the interrelation with the environment. This perspective may be transposed to the behavioural and social field. As Bunge (2004: 73) states, this theory refutes materialism without renouncing to the physic and physiologic basis of the cognitive processes. It is consistent with "(…) the hypothesis that the mental processes possess peculiar characteristics which differentiates them from other bodily functions."

Taking as a reference the perspective of Edgar Morin (1992), I consider the systemic perspective applied to cognition, not as a general systems theory based on a holistic perspective, which would be reductionist, but as a systems theory in 'generic' and 'generative' terms, allowing to understand all the conceptual complexity and as such avoiding the reduction of what is complex to a concept or a holistic simplifying theory. With Morin (1992: 373) we think that the system shouldn't be conceived simply as a global unity but rather in terms of a *unitas multiplex* "(…) the examples of atomic, biological, and social

[1] We consider the dynamical systems theory as a metatheory in the sense that it defines general methodological rules for the approach to the phenomenon in general, as such, it is transposable to different knowledge fields, and it represents a general and flexible theoretical-methodological framework that can be applied in different research fields (Gutiérrez, 2005). It is also a new way of thinking which stimulates a complex *praxis*.

[2] The complex systems are 'self-organized' in the sense that it is their own functioning which generates their new states. The systems, understood as non-linear, are open and in permanent interchange with the environment. They are able to produce new states qualitative distinct from the preceding ones. The non-linear change underlying all the evolutionary transitions is dynamic, probabilistic and floating, in sum, emergent. The systems are plastic because they are emergent, non-linear and composed by relations at different levels.

systems show us that a system is not only a composition of unity out of diversity, but also a composition of internal diversity out of unity."

In this context we understand that, although in the language of science metaphors are inevitable (Lewontin, 1998), some metaphors are more appropriate than others for the study of cognition and learning.

1. Systems theory contributions for the study of cognition and learning

The works of Maturana (1980, 2003) and Varela (1991, 2003) are at the origin of the study of cognition as a biological phenomenon. The Santiago Theory established that the circular organization of the nervous system corresponds to the basic organization of all living organisms, whose evolution is characterized by circularity, self-organization and self-referentiality. For Maturana: "The living systems are cognitive systems and the process of living is a process of cognition. This statement is valid for all the organisms, with or without a nervous system." For Maturana and Varela the organisms are *autopoietic* [3], in the sense that they are self-creators. The study and comprehension of the organisms should be centred on processes and relations happening between the components of the system, and not on the components' properties.

Maturana and Varela perspective recognizes the connections between knowledge, life and individuals' experience. Knowledge is contextualized, concrete, embodied and lived, endowed with uniqueness and historicity. Cognition is '*ennaction'* once that the structure of the human being, as a living organism, makes possible the interaction with, and the construction of, the exterior. Compared with the classical scientific thought, systemic thinking emphasises relations, instead of objects, quality instead of quantity, and pattern instead of substance.

These contributions, together with chaos theory and fractal geometry, gave progressive consistence to dynamical, non linear and self-organized systems perspective, as well as they connected in a strong sense cognition with the development of the processes of living – cognition is a vital process which implies biological, physical, emotional, psychological and social factors. For the emerging living systems theory, the vital processes are identified with cognition, the process of knowing, implicating a new concept of mind, transcending the Cartesian division between matter and mind: matter and mind are two dimensions of the same phenomenon of life. Mind is not a thing, it is a process: the process of life. The interactions between an organism and its environment are cognitive, mental interactions. Life and cognition are inseparably entailed. The mental phenomenon is a systemic phenomenon characteristic of all living organisms. The phenomenon of mind is, according to this perspective, inseparably bound to the phenomenon of life. Although having some diffuse aspects, Santiago Theory, has been complemented by different theories and perspectives like chaos theory or complexity theory and revolutionized the way we think about development and cognition. Its systemic approach had profound consequences in both natural and social sciences' research. Systemic thinking emerged as a scientific paradigm in which the epistemological perspective is connected with ontological postulates about the nature of the organisms and their processes of evolution.

However, there are some divergences among authors about the defining criterion for systemic thinking. For instance, while Capra (1996) defines systemic thinking as holistic, Bunge (2004) or Morin (1992), refuse this idea as reductionist or superficial, and argue that systemic thinking is integrative, contextual, but not holistic. Both authors say it is partial without being reductive, it's complex but not only general, it is 'generic' and 'generative'.

[3] 'Autopoiesis' means 'self-creation', it represents, for Maturana & Varela the common organization of all living systems, it is life pattern, the organization pattern of all living systems, it is the defining characteristic of life according to this theory. Cognition and 'autopoiesis' are two distinct aspects of the same system of life. It presupposes the idea of network. It is, in a certain way, connected with the connectionist perspective in the way that it is interested in relations and not in the systems components, however, by contemplating structure it includes embodiment. The networks, in which systems theory is based, as understood by Santiago Theory, are concrete and not formal abstractions of the living systems.

Beyond these divergences they all agree that complex thinking deals with emergencies, is constituted by levels and focus on relations.

Some authors consider the systemic perspective as a metatheory (Gutiérrez, 2005), or as an 'umbrella concept' (Jörg, Davis & Nickmans, 2007) once that it can be applied to the study of different phenomenon – biological, psychological or social. It is simultaneously a world view and a methodology, which may be applied to the study of the different phenomenon involved, brings together ontology and epistemology (Bunge, 2004; Capra, 1996). I would say that dynamical systems theory offers a theoretical and methodological framework in which to situate the research about development and cognition in a broader horizon of relations and in an integrative perspective. When related with the other models, its advantages concerning the comprehension and explanation of development and cognition are:

1. The possibility to surpass dualisms and to explain the systems evolutionary dynamics in terms of relations, connections, contexts, offering a multidimensional perspective of the processes and factors influencing and determining cognitive development;
2. The account for the material basis and dimension of the cognitive processes, avoiding physicist reductionism, allowing the analysis of mental processes without falling into functionalism;
3. By assuming the existence of emergent properties and systems, explains novelty, change and evolution in relation with the environment and the emergence of new systems;
4. Integrates, in what concerns living organisms, biological, psychological and social dimensions without reducing one of them to the others.

Opposite to computational systems or to the psychological perspective, which compared the human systems with natural systems ignoring specificities, complex systems perspective allows, in what concerns to the study of the mind, to integrate the social, socio-cultural and historical dimensions in the comprehension of human systems. This means to abandon the pretension of creating an explanatory model for the 'universal' mechanisms of the mind, ignoring the influence of social and cultural practices in formation, development and differentiation.

We think that the systems theory offers to the study of cognition:

a. A systemic approach to development;
b. A systemic approach to the brain as the seat of cognition; based on the neural plasticity model;
c. Shows the need of a trans-disciplinary approach (OECD, 2002, 2007) to cognition and learning which must take into account the complexity and multidimensionality of the learning subject, the learning processes and contexts.

2. The plastic brain model – a systemic approach to cognition and learning

Self-organized systems are plastic because they are mutable, they are in permanent interaction with the environment, and they have a history and a complexity degree which is not compatible with reductionist metaphors. All the living organisms, as well as the brain, are self-organized, plastic and complex. In the living organisms plasticity manifests itself as phenotypic plasticity [4], in the brain, plasticity manifests itself as neuroplasticity, which is an example of phenotypic plasticity and one of the central characteristics of the brain, as the seat of cognition.

In this context, individual development trajectories are not, neither genetically programmed, nor divided into normative stadiums, nor related with any static variable. Human beings, as self-organized systems, are multidimensional and plastic; they are constituted by a myriad of genetic, physiologic and psychological attributes. Behaviour is the result of the interaction between their different attributes with a certain environment, contextualized by the task at hand in a certain moment (self-organization in real time). The

[4] Phenotype understood as genotype expression (genetic information) in a certain environment (phenotype = genotype + environment).

emergence of skills, schemas or personality patterns represents configurations that have crystallized over many occasions, yielding developmental forms and habits (self-organization in developmental time). These habits may be modelled as attractors for behavioural states in real time (Howe & Lewis, 2005). In dynamic systems theory terms we could say that developmental structure determines the 'state space' of possibilities in the moment, in real time.

Cognitive neuroscience represents a systemic approach to the brain, because it is based on the recognition of its plasticity – central property of the nervous system and the key of the mind (Bunge, 2004) –, complexity and developmental multidimensionality. It integrates the systemic perspective of development in the understanding of the brain as a plastic brain. This model recognizes the complexity of brain functioning considering the genetic, social and learning factors. It is concerned with implementation and, as such, with cognitive processes physical dimension.

The new idea of the brain as the seat of cognition, consciousness and personality represents also the need of a new perspective about the factors influencing the cognitive processes in their various dimensions. To think about the mind-body problem, the relation between thought and emotions, or the role of memory and language implies to think cognition in its multidimensionality. The implications of this understanding of plasticity go beyond the strict limits of science and pose educational, social and even political questions.

In scientific terms plasticity refers to neuron's capacity to reorganize their synaptic connections in response to an external or internal stimulus. This modification can be permanent, persisting through time. Plasticity designates brain's continuous openness to environmental influences, and that this relation brain-environmental is determinant to brain's development. It shows that human brain it's simultaneously genetically determined – in terms of its structure – and modeled by experience. Neuronal development is the result of the conjugation between genetic and epigenetic factors. In neuronal terms, plasticity involves different factors, levels and conditions. Its main traits and implications could be organized as fallowing:

1. Brains have the capacity to change, adapt, and learn throughout the life span. Plasticity underlies and accompanies learning;
2. The brain changes responding to environmental stimulation, which means that it is not completely determined since the beginning. Those changes are determined by the conjugation of genetic and epigenetic factors;
3. Plasticity implies periodicity, in the sense that there are sensible periods or "windows of opportunity" which favour or difficult certain changes;
4. Plasticity has its limits related with brain functioning and organization (neurogenesis and apoptosis).
5. The brain functioning is plastic and its organization is integrated;
6. The use we make of our brain determines its development.

Some of the main brain properties and functions known in nowadays are: the unusual level of spontaneous activity, the lateral inhibition of nervous tissue, the neurons aggregation in systems, the functional differentiation and relative independence of some brain subsystems, and the plasticity of certain interneuron connections, which is the key of behavioural and social plasticity. The study of the brain functioning shows it, not only as a self-organized [5] system, but also as an extremely complex 'system of systems'.

The concept of plasticity expresses the essential tension between human beings openness and closure, expressed in the own development of the brain. There are in the brain elements of rigidity and of plasticity, conjugated to facilitate development. Plasticity has a double dimension: on the one hand, it is conditioned, however it is not determined in absolute by genetics, on the other hand, it represents our brains' openness to experience, to possibility. The limits and possibilities underlying neural plasticity are simply the reflex of the restrictions, limits and conditions of human nature and existence, evident at many levels and dimensions.

[5] Self-organization is the property of some physical systems with multiple constituents to exhibit non-predictable behaviour, in some cases, with growing adaptability.

All these issues should be transposed to educational field and be a reference to the reflection about the educational implications of this paradigm shift. Cognitive intervention and education should be thought in the framework of brains' plastic capacity and the factors which determine its development, taking into account that the human subject is a complex subject which development occurs at various levels and it is determined by different factors.

Education should be oriented to multidimensionality and complexity. There is a close connection between these two concepts, in the words of Edgar Morin (1999: 13): "complex units, like human beings or societies, are multidimensional; the human being is simultaneously biological, psychological, social ,affective, rational.", and being complex implies the very unity of these various dimensions.

From a systemic point of view, multidimensionality can be thought at different levels:

1. At a first level we have the relation between biology and culture, the human being is a bio-psycho-social being, and in between the brain/culture relation emerges the mind. Consciousness is an emergent property of the brain in its relation with the world of culture;
2. At a second level there is the relation between reason and emotions interacting either as complementary and antagonist (cooperation and tension; balance and conflict);
3. Finally, there is the relation between individual identity and the social dimension of human existence, the dynamics identity/difference.

Understood in this way, the subject is bimodal (Asensio, 2006; García Carrasco, 2007), his nature and complexity situate him in between biology and culture, genetics and environment, reason and emotions, subjectivity and inter-subjectivity, *sapiens* and *demens* (Morin, 1999). In cognitive terms we conceive the subject as multimodal (Smith, 2005) in its experience and in his relation with the world.

3. Promoting trans-disciplinarity – some epistemological questions

Transposing the complexity and plasticity metaphors to the educational field implies to think in which way distinct languages, concepts and discourses can be conjugated in a complementary relation in order to surpass the existing semantic fracture between sciences and humanities (Ferry & Vincent, 2001; Changeaux & Ricoeur, 1999). It is also important to discuss the nature of the relation between fields of knowledge thinking contributions and relevant findings in each discipline, especially in educational theory and practice, in order to propose future collaborations.

Concerning the first question I think that the emergence of a plastic and multidimensional subject, the new theories of cognition and cognitive development, and the need to incorporate a change theory to face the growing and diverse problems and questions arising in educational practice, demand new research paradigms and intense cooperation between disciplines.

I argue that if we recognize the systemic nature of some educational problems of our times we should also defend and promote a trans-disciplinary approach to such problems. Complexity demands convergence.

Educational Science must depend on many other disciplines and inter-disciplines because:

1. The brain is plastic and capable of learning throughout the life span;
2. The learning subject is multidimensional and complex;
3. The learning processes are complex;
4. The subject has a mental life and he is inserted in complex and changing social networks;
5. Human beings occupy different organization levels, from physical to social, which is the reason why they can't be understood if we centre our attention only in a single level;
6. Learning sciences and pedagogy need a scientific basis which fundaments research and sustain teachers action, their techniques and strategies of intervention;

7. Educational research is transversal and, as such, demands a considerable effort, efficient teams and effective results, which must be financed by governments and administrations.

According with the conceptual framework defined here we conceive with Jörg, Nickmans & Davis (2007) that the relation between cognitive sciences and educational sciences should be trans-disciplinary and inter or trans-discursive. If we consider that cognitive neuroscience has originated some key ontological concepts – such as neural plasticity, the neural basis of mental processes, parallel integral architecture – which have important implications for the understanding of the educational institutions, learning processes and the learning subjects, we can easily admit the need of convergence between education and the cognitive sciences, in order to better understand the new emerging reality.

It is not a matter of denying the importance and the need of specialization and some particular sciences knowledge importance and contribution. Both specialization and integration are necessary, and each one emerges to correct the excesses and limitations of the other. In the words of Mario Bunge: "Specialization is demanded because of the world's diversity and the growing richness of our mental tools, while integration is needed for the contraposition between knowledge fragmentation and the unity of the world." (Bunge 2004: 335)

However, we must recognize that the evolution of the scientific knowledge has been, in a significant way, directly related with the capacity of some sciences to cooperate and fusion with each other. One of the most recent and productive examples is cognitive neuroscience, which is the result of the fusion between psychology and neurobiology. Furthermore, the dimension of the challenges faced by educational systems in nowadays, and the progresses made by cognitive sciences in the understanding of the brain and the learning processes, are supportive of the need of a straight cooperation. On the one hand, most of the educational systems face the difficulty to adapt themselves to the emerging problems and profound changes brought by globalization. Also the fast and complex social and political transformations of the 21st century made clear that a different, more systemic approach to the educational questions is necessary. On the other hand, progresses made in the last decades on the cognitive sciences may offer the concepts and tools needed to undertake the necessary educational change.

In the OECD document *Understanding the Brain: towards a New Learning Science* published in 2002, the problem is presented in the fallowing way: "The more we learn about the human brain, especially in the early years, the less comfortable we find ourselves with the traditional classroom model and imposed curriculum of formal education" (OECD, 2002: 14). Emergent complexity requires new institutions, new curriculum, new methods and new knowledge. As it is said in the before mentioned document: to unravel the complexities of human brain, understand the nature of memory and intelligence and what exactly happens when learning occurs, are some of the main goals that can be achieved through the collaboration between learning and cognitive sciences. They can help us to refund our practice of education on a solid theory of learning. "In particular they can shad new light on old questions about human learning and suggest ways in which educational provision and the practice of teaching can better help young and adult learners." (OECD, 2002: 27). In this sense, such collaboration may also represent an opportunity to reorganize education institutions and rethink research priorities.

Trans-disciplinarity, understood as unification through fusion (Bunge, 2004), not through reduction, implies bridging and fusing in a new comprehensive discipline different scientific procedures, methods and findings, which will also require new methodologies and new research organizations. The possibility of a new learning science based on a trans-disciplinary approach depends on the capacity:

1. To create a common language, defining and integrating concepts of different sciences;
2. To establish new research priorities and institutions;
3. To open the debate to other disciplines;
4. To distinguish between what is well established, what is probable and what is a myth about the brain functioning and the learning processes;
5. To promote the practical application of neurosciences knowledge;

6. To promote research based on the problems coming from educational practice and pedagogy,
7. To establish common methodologies.

In the scope of complex systems theory trans-disciplinarily represents a (re)foundation of educational theory as complexity theory, referred to a new research attitude opened to different discourses and searching for more comprehensive perspectives. In the practice of trans-disciplinarity should converge in the same project, different perspectives and disciplinary concerns in the search for common questions.

Conclusions

Some key-concepts for the understanding of cognition and cognitive development we have been analysing may function as 'bridge-ideas' for the convergence of different disciplines.

1. By offering a metatheory which integrates different perspectives and dimensions of cognition, **complexity** is an articulating concept. It is a framework for research in education, beyond reduction, dualism or simplification;
2. The concept of **system**, supports a systemic understanding of the subject of education and underlies a systemic approach to educational phenomenon, introducing as well the concepts of multi-levels, non-linear processes and self-organization, connecting thinking in human sciences with the living organisms functioning and biology;
3. **Plasticity**, represents a new metaphor of cognitive functioning and development, connected with brain functioning, a new understanding of the relation between nature and culture, that introduces the physical dimension of cognitive processes and explains and fundaments the capacity of learning throughout the life span, at the same time introduces the idea of periodicity and limits. Thinking the subject as a plasticity subject opens a common field for the research in educational sciences and cognitive sciences;
4. **Trans-disciplinarity** is a epistemological concept which characterizes the possibility and need of the relation between cognitive sciences and educational sciences and justifies the need of new methodologies and new research institutions;
5. The concept of **inter or trans-discursivity** emerges from complex thinking and it is intimately connected with the idea of trans-disciplinarity, it is based on the need to conjugate different languages and discourses in order to achieve a better understanding of education and human skills.

These concepts, analysed within the framework of the new paradigm, represent multiple possibilities for the future of both educational practise and scientific research. I would like to point out some of them: the recognition of the importance of an appropriate scholar process to the development of the brain; the personalization and organization of the educational processes attending to the complexity and diversity of the subject's mental styles; the practical application of the neuronal principles of learning in order to rethink strategies, atmospheres and learning models; the promotion of a rich and adequate stimulation since early childhood and a long life synaptic stimulation; as well as the promotion of an integrated development of individuals faculties respecting and promoting cognition's different dimensions – intellectual, social and physical; develop the study of the physical processes which determine learning, parting from the brain's functioning explicative theories and to apply them; and to rethink cognitive training, adapting it to the new data emerging from research.

References

1. Bunge, M., *Mente y Sociedad. Ensayos Irritantes,* Alianza, Madrid, 1989.
2. Bunge, M., *Emergencia y Convergencia: Novedad Cualitativa y Unidad del Conocimiento,* Gedisa, Barcelona, 2004.
3. Capra, F., *La Trama de la Vida*, Anagrama, Barcelona, 1998.
4. Changeaux, J. P.; Ricoeur, P., *La nature et la règle : ce qui nos fait penser*, Odile Jacob, Paris, 1999.
5. Crespo, A., *Cognición Humana. Mente, Ordenadores y Neuronas*, Ediciones Centro de Estudios Ramón Areces, Madrid, 2002.
6. Ferry, L.; Vincent, J. D., Qué es el Hombre?: Sobre los fundamentos de la biología y la filosofía,Taurus, Madrid, 2001.
7. Gutiérrez Martínez, F. *Teorías del Desarrollo Cognitivo*, McGraw-Hill, Madrid, 2005
8. Howe, M. L.; Lewis, M.D., «The importance of dynamic systems approaches for understanding development», *Developmental Review*, 2005, 25, 247-251.
9. Jörg, T.; Davis, B.; Nikmans, G., «Towards a new, complexity science of learning and education», *Educational Research Review*, doi: 10.1016/j.edurev. 2007-09-02.
10. Lewontin, R., *A Tripla Hélice. Gene, Organismo, Ambiente*, Edições 70, Lisboa, 1998.
11. Maturana, H., «Biology of Cognition», *Autopiesis and cognition*, D. Reidel, Dordrecht, 1980.
12. Maturana, H.; López, M.; Pérez, A.; Santos, M., *Conversando con Maturana de Educación*, Ediciones Aljibe, Málaga, 2003.
13. Morin, E., «From the concept of system to the paradigm of complexity», *Journal of Social and Evolutionary Systems,* 1992, 15 (4): 371-385.
14. Morin, E., Los Siete Saberes Necesarios a la Educación del Futuro, UNESCO, Paris, 1999.
15. OECD, *Understanding the Brain. Towards a New Learning Science*, OECD, Paris, 2002.
16. OECD, *Understanding the Brain. The Birth of a Learning Science,* OECD, Paris, 2007.
17. Smith, L. B., «Cognition as a dynamic system : Principles from embodiment», *Developmental Review*, 2005, 25, 278-298.
18. Varela, F. J., Thompson, E.; Rosch, E., *The Embodied Mind: Cognitive Science and Human Experience*, MIT Press, Cambridge, 1991.
19. Varela, F.J., «Comment articuler la pensée avec l'action», J. F. Dortier (coord.), *Le Cerveau et la Pensée*, Éditions Sciences Humaines, Auxerre, 2003, 389-395.