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The Complex Thinking: building of a new paradigm

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building of a new paradigmPhysician, Doctor in Physics, researcher in Contemporary Physics teaching and in complex approaches in Education. Associate Professor of the Institute of Physics at University of Sao Paulo, Sao Paulo, Brazil.

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Complexity is a term that in recent decades has designed a wide range of procedures and approaches to address problems in science. More recently they have been employed in many areas of knowledge. In general, complexity seeks to walk the difficult path of simplicity (reductionism) and strict causality, to better representation of reality, i.e. the things of the world. Many believe, including this writer, that the complex would consist of a new paradigm based on science. This text is far from exhausting the subject; we present some aspects of this thinking, including conceptual and epistemological considerations and applications. It lends itself as a first guide for exploration. So they are not provided references for further throughout the text, they appear at the end, grouped by topic or by author, in a similar way as places to be visited during an exploration trip.

Foreword

The complex thinking dedicates itself in thinking about phenomena where several factors interact, where principles of regulation and non-equilibrium are combined, where contingence and determinism, creation and destruction, order and disorder are; where levels of organization and non-linear dynamics can be identified by feedback between the levels.

The life of an animal can be used as an example to explain concepts as the levels of organization and feedback. The animal could be defined, in a simplified way, in three levels: a wide or superior level (the animal as a whole), an intermediary level (organs), and a basic or lower level (DNA chemistry). In this case, a superior level cannot be explained entirely by separating its constituent elements and by interpreting its properties not considering the interaction that unites the elements and the levels. The system's history, i.e., the animal's life, is not reducible to structural factors.

Complex thinking does not assumes that 'everything is complex', meaning 'what cannot be understood'. It is not a though of the imprecise and the uncertain, despite it includes imprecision and uncertainty. Its goal is to work as a base to help on building concepts and methodologies – thinking tools, reflection and action in the world –, to articulate expertise knowledge. The complex though is not a 'finished theory', but a conceptual tool that is being elaborated.

Complex thinking is not "holistic", focusing on the global instead of the analyses of the particular, of the elements. It aims at articulating the whole and the parts, the global and

the particular in a never-ending flux of going and coming.

Complex does not mean complication. A car is a very complicated machine, but it can be decomposed in a finite set of pieces. On the other hand, a live organism, or an historical phenomena are complex, in the sense they cannot be decomposed and reconstructed starting from simple and independent elements, without considering the feedback in-between the levels of organization.

A little bit of history

The scientific knowledge "goals", until the half of the 20th century, were the discovery of nature's necessary and universal laws in a reductionist connection. Primarily it was supposed to be always possible to reduce the explanation of the properties of a system constituted by a large number of elementary interacting units to the knowledge of its simple properties of these units.

Mainly from the sixties of last century or even from the last decade, it is observed that structurally identical systems can manifest distinct behaviors under diverse conditions. It starts to occur, in a manner of speaking, of what some authors call renunciation of epistemological priority of categories as simplicity, order and regularity in favor of categories as complexity, disorder and chaos. Note that it is placed in terms of "renunciation of epistemological priority", which does not mean that simplicity, order and regularity are detached, but incorporated in a larger epistemological framework.

In particular, it is verified that it is possible that an unpredictable behavior (chaotic) from very simple models (few degrees of freedom) and represented by non-linear precise rules (deterministic systems): it is what is called deterministic chaos.

Falls to the ground, definitely, the fundamental myth of 18th century science: the predictability of nature.

The emergence of the complex thinking occurs a little before the 1930s, in the contraposition of two approaches in the study of living organisms: the evolutionary biology (heiress of Natural History) and the functional biology. The functional biology has a reductionist character and attempts to explain biological phenomena from events that occur at the molecular level, trying to reduce the biology to chemistry and to molecular physics. The evolutionary biology – from which the ideas of complexity emerge – treats the living organisms as indivisible entities; specific particularities emerge only at the level

of the whole organism and are not deductible, no more than some aspects, of the analysis of the constituent subunits.

In the following decades occur developments that will constitute the bases of the complex thinking, resulting from the intersection of diverse theories. In the 1940s, cybernetics, information and communication theories will furnish the bases of a theory of the organization. In the 1960s, the works of the physicist-chemistry Ilya Prigogine (study of the open systems distant from equilibrium), of the mathematician John von Neumann, of the physicist Heinz von Foerster and the doctor and philosopher Henri Atlan (order from noise) will provide the elements of a theory of self-organization. In the 1970s and 1980s, the theory of deterministic chaos, more than to reunite determinism and unpredictability, promoting a new vision of processes, will provide a conceptual framework and original and powerful mathematical tools to deal with phenomena of nature and society, which one, until this moment, were not very well understood. These theories will constitute the bases of the complex thinking.

The world's complexity and the complexity of the models of the world

The complexity provides a new image of nature and society. The vision of a universe conceived as clockwork opposes to the one of a living being, at the same time more unstable and unpredictable, but also more open and creative.

The natural sciences broadly utilize models for complexity. A significant part of the concepts, available today, were firstly developed in physics, specifically the fluids and lasers, in the study of systems of several particles away from thermodynamic equilibrium. As a result some of the manifestations of the complex thinking could be perceived as a shift in the focus of the topics concerning the physics of condensed matter, starting from the sixties – a field that was before it more focused on the study of gas and solids with regular structure and fixed composition, and that starts studying amorphous systems and liquids.

Besides many applications in physics, the models for complexity are applied in several other natural sciences. In chemistry, for instance, concepts of chaos theory and self-organization are used in the study of oscillating chemical reactions, with the emergence of complex spatiotemporal patterns. In biology and ecology, sophisticated nonlinear models for population dynamics are constructed, in which ones microscopic variability (fertility and longevity) adds randomness (births and deaths) and mutations to produce dynamics in which these factors are simultaneously causes and products of evolution.

Sophisticated models were also used in epidemiology and immunology, where several factors are taken into account, imitating complex behaviors and results applicable to real world situations. In medicine, particularly in the study of atypical heart diseases, through the analysis of electrocardiograms, and in the study of neurological disorders from the analyses of EEG signals of epileptic patients, concepts and methods of the theory of deterministic chaos are being used, occurring in some situations, the emergency of self-organization in large scale. In neural sciences enormous progresses have been verified in recent decades, credit to the construction of models for brain dynamics.

In human sciences, the applications are more recent but no less exciting. From a complexist perspective, the economy, as an example, corresponds to a non-linear dynamic generated by a multiplicity of interacting forces (the role of the government, of the technology, action of social groups, culture, etc.). The dynamic can converge creating self-organized patterns or destroying regular structures. In both processes there are moments of stabilization, feedbacks (positive or negative), moments of destabilizing and bifurcation of uneven development poles, and so on.

The chaos theory is used in models of growth, crisis or fluctuation. Instead of considering the market as a self-equilibrium system (the neo-classical model), the aim is to find unstable elements in the stock exchanges or other markets. In this case, according chaos theory's concepts, infinitesimal variations in the evolution of prices or the emergence of a rumor, could lead the market to a far from equilibrium state, since a critical mass is reached.

In management sciences there are attempts to use systemic and complexity models to understand changes in the Corporations (caused by crisis or by regulation) as well as decision problems and practical applications derived from these problems. There are also studies of risk in society in order to anticipate possible damage caused by a decision as the risks of investing in regions with a development program, risks concerning the banking system, risks involving technological innovation, risks in road traffic, and so on.

In the legal system, the courts, legislation, law cases and accommodations with the political system are considered preceding a system analysis in a complex perspective as a self-referential process in which dynamic there are reciprocal feedbacks between higher and lower levels in a logical loop, which is, by the way, a typical characteristic of complex systems.

In psychopathology there are attempts to interpret psychological problems as an

articulation between the physical, the emotional and the social systems, in the processes of personality construction.

In geography and socio-economy there are attempts of interpreting the 'world system' as a complex architecture where are observed several levels of organization (local, national, international), various systems of (financial, economic, geopolitical, demographic, ecological, and ideological) action. It is a matter of identifying the subsystems to, in sequence, rebuilt the interconnections.

In prevision, it is not a matter of extending the ongoing tendencies (economic growth or population growth) in order to predict the future. The actual models are more similar to the models of the weather science than to the ones of the ballistics. There are allowed scenarios with bifurcations, with transitions, stable states, interactions between political, economic and monetary levels. Nevertheless, it does not mean that ‘everything is possible" and that, therefore, nothing is predictable. According Lesoume "the future is the meeting of determinism, chance and the will." (J. Lesoume). It is a matter of seeking a balance between strong connections, the more uncertain tendencies and the moments of important and viable changes to draw the outlines of several scenarios that are more or less probable.

In sociology, the complex thinking appears as an exciting method to integrate the changes and theoretical innovations of recent decades, leading to a better understanding of the social that is *par excellence* the domain of the interpenetration. Some authors attempt to explain the fact that the society has a relatively ordered and regular dynamic, despite being constituted by autonomous individuals. These authors use the ideas of self-organization of the market (Adam-Smith) and self-organization theories.

In education, one has to recognize and reaffirm the pioneering of the Piaget’s already complex thinking. More recently, some authors have tried to build *curricula* and methodologies that enable the transition from a simple thinking to a complex one. The search is for a complex perspective of the world that allows to overcomes notions based on strict and linear causality that are often present in educational practice as well as in the textbooks; A complex perspective that addresses the need to overcome the process of knowledge fragmentation. The interdisciplinarity has a more precise meaning in this context concerning the learning process. The selection and organization of school contents from a systemic and complex perspective become essential and have been treated by some authors.

Guidelines in the theoretical and the epistemological realms

In a theoretical realm, four points outline the complexist orientations: the *systemic*, which one avoids the weaknesses of the mechanistic approaches of the strict causality; the *consideration of an irreversible and non-linear historicity*, made of ruptures and continuities, running away from the structuralism, the *pragmatic*, evidencing the actors, the actions and intentions, allowing in to avoid the intellectual impasse that reduces men to the state of inert agents of their future; the *hermeneutics*, in the precise sense of the examination of all human activities as a set of discourses and meanings, opening new perspectives in a domain blocked before by the primacy of material forces.

From the epistemological point of view, the complex thinking is characterized by three fundamental attitudes: the insistence on the need for vigorous theoretical efforts to face an empiricism and eclecticism still very present in the quotidian research life: one must understand the need for invent and make novel discursive and conceptual objects; the constructivist orientation that instead of positivism leads in the direction of conceptual imagination; the reintegration of knowledge production in the society, avoiding an excessively abstract epistemology, far away from sociology and the history of science (explaining the social by the social).

Complex thinking: principles

In this next session, I follow the trails of the thinking of the anthropologist Edgar Morin. The complex thinking presents itself as a building of several floors. As explained before, the base is built starting from three theories – information and communication theory, cybernetics and system theory – and includes essential tools for a theory of organization. In a second floor are the contributions from von Neumann, von Foerster and Prigogine, concerning the ideas of self-organization, and the concepts chaos theory. One can add supplementary elements in the form of three principles proposed by Morin [1]: the Dialogical Principle; the Principle of Organizational Recursivity; and the Hologramatic Principle.

Through the Dialogical Principle, two antagonistic processes or concepts, that should refuse one another, are united in a complementary way, essential and inseparable to understand a given reality. Two antagonist notions are united then to think the organizational, productive and creative processes in the complex world. The dialogic notion in Morin involves complementarily, antagonism and competition between the elements that are in dialog. The notion of dialogic extends that of dialectic. They are

exemplifying pairs in dialogic: order / disorder, junction / disjunction, universal / particular, and so on.

The Principle of Organizational Reclusiveness goes beyond a Feedback Principle of the systems theory and the cybernetics (feedback). The notion of regulation, present in the Feedback Principle, is extended by the notion of self-production and self-organization. It is, so to speak, a generative ring in which the products and the effects are, themselves, the creators of what produces them. Is this way for instance that we individuals are products of an ancestral breeding system, but this system cannot reproduce itself unless we ourselves are the producers. Human beings produce society within itself and by their interactions, but the society produces the humanity of these individuals providing them with the language and the culture.

The Hologramatic Principle highlights the apparent paradox of certain systems, where not only the part is in the whole, but the whole is in the part. Each cell, for instance, is part of a whole - the global body - but the whole itself is also in the part: the entire genetic heritage is present independently in each cell. Likewise, the individual is part of society, but society is present in every individual through language, culture and its norms.

Complex thinking and classical science

The classical scientific thinking was built on three pillars: the order, the separateness and the reason. The complex thinking, far from replacing the idea of order by the one of disorder, or vice versa, aims to put in to place in a dialogical perspective , order, disorder and organization (dialogical as explained in the previous section). The ideas of order and disorder are no longer excluding each other; organizational order can emerge from the turbulence and disordered processes can arise in deterministic contexts.

The notion of separateness corresponds to the Cartesian principle according to which to study a phenomenon we should break it down into simple elements. One consequence of this is the idea that the objective reality can be considered without regard to the observer. However, quantum physics has shown through the Uncertainty Principle by Heisenberg that the observer interferes with the observation. The complex thinking does not substitute separateness by inseparability, but calls, once again, on a dialogic that uses the separable, but inserting it in the inseparable.

The third pillar of the classical reason rests on the principles of induction, deduction and identity, that is, the rejection of contradiction. The first blow against the induction was

given by Popper; the induction has a heuristic value, but has no the value of an absolute proof. For instance, one cannot induce a universal law as "all swans are white" from the fact that he never have seen a black swan. The blow against the deduction was given by Gödel's incompleteness theorem, which one shows that a formalized deductive system, the mathematics, cannot find in itself the demonstration of its validity. The same is shown by Tarski in the semantics logic, concluding that no one system has enough methods or ways to self explain.

Finally, regarding the incorporation of contradiction in scientific theories, the Physics incorporates the two times contradictory nature of the particle (wave / corpuscle). The complex thinking calls, not for the abandonment of inductive-deductive-identity logic, but for a dialogic combination between their use segment by segment and its transgression where it ceases to be operational.

A new paradigm in construction

Concluding, it can be stated that the scientific developments in recent decades have held some surprises. For instance, complex systems composed of many parts may, under determined conditions, show orderly behavior. On the other hand, very simple systems can show complex chaotic behavior.

Results like these, and many others in contemporary science, besides the first attempts to revisit the human sciences from a complexist perspective, provide the basis for the construction of a new scientific paradigm.

In fact, in order to not lose sight of the vision of knowledge construction as a historical process built together by several hands, one should emphasize the premises of a complex thinking in the history of the Western philosophy, as appropriately pointed out by Edgar Morin. In the Greek Heraclitus, is already present the need to involve a series of contradictory terms to affirm a truth. In Pascal, in his "Thoughts", the French philosopher said: "Everything, being helped and helper, caused or causes, I consider being impossible to know the whole without knowing all the parts and know the parts without knowing the whole." Kant highlights the limits or "*aporia* of reason." Spinoza already considered the self-production of the world. Hegel´s dialectic announces the dialogic. Nietzsche raises the first crisis in the foundations of certainty. Adorno, Horkheimer and Lukács, from the *Frankfurter School*, bring the elements of the critique of classical reason, and also the ingredients of complexity thinking.

The Complex Thinking do a constant coming and going between certainty and uncertainty, between the elementary and global, between the distinguishable and indistinguishable. In the construction of the new paradigm it is not a question of abandoning the principles of classical science – order, separatness and inductive-deductive-identity logic – but to integrate them into a schema that is at the same time wider and richer. It is not a question of abandoning reductionism or strict causality, but to use them when it does not blemish the understanding of the object or studied system, combining the object/system with its complex aspects, when present. This is not about to deny disciplinarity and specialization in confrontation with multidisciplinarity or interdisciplinarity, but to use each one of it when the problem to be solved requires it. This is not about to opposite a global holism to a systematic reductionism; it is about to link the materiality of the parts to the whole. It is about articulating the principles of order and disorder, separation and junction, autonomy and dependency, which ones are in dialogic, i.e., which ones are complementary, rival and antagonistic.

Itineraries to a travel through complexity: a bibliography [2]

As in a travel guide, it is always difficult to propose a first place to be visit. The guide provides at most a few touring options. It is for the traveler to choose one. Remains however in the traveler's mind, the impression that another option, perhaps, would have been more interesting, or, as time does not allowing to see everything, remains the desire and emotion of the future return. Here the situation is no different, in particular by being complexity a theory in construction and utilized in many areas of knowledge. Sometimes, these applications do not occur in traditional disciplines, but in multidisciplinary or even interdisciplinary approaches. It makes everything difficult. The traveler experiences the uncertainty of penetrating nebulous regions, where he identifies some elements, but others seem to be obscure. Maybe some precaution is convenient to the guide: do not seek shortcuts which are unknown, leaving to the traveler the option of choosing the paths, alternatives, to allow him in to participate in the construction of your own walk. It is in this sense that the bibliography here proposed is given. It is an introduction and has no the concern of selecting the latest works published. The only caution I had is that it was relevant and correct.

I imagine some entries to the complexity. One is through epistemology, through the method. There are travelers who believe that it is the safest course. Others, however, by their specific training or by temperament, judge this entry too far from the real world. Although not thinking that way, I understand that position, especially taking into account

the training we have been offering to our students, where epistemology is largely absent from university curricula.

The epistemology entry can be through two great authors. One, already mentioned in this text, is Edgar Morin. This remarkable intellectual, on one occasion, responding to my assertion that, from my perspective, his importance in building the foundations of complexity is similar to the importance of Descartes to the classical science, told me without false modesty: "It is with this expectation that I work." The work of Morin is vast and of excellence. His major contribution lies in the monumental "La Methode", a work written over several years and published in six volumes:

MORIN, E. **La Méthode** (6 volumes), I. 1977, **La Nature de la nature**; II. 1980 **La Vie de la vie** III. 1986, **La Connaissance de la connaissance** (Theorem) IV. 1991, **Les Idées. Leur habitat, leur vie, leurs moeurs, leur organisation** V. 2001, **L'Humanité de l'humanité** (t. 5), 1**. L'identité humaine** VI. 2004, **L'Éthique complexe.**

Another book by Morin, previous to The Method, is easy to read and presents an outline of his future work, stating quite clearly the central elements of his thought:

MORIN, E. ***Science avec conscience.*** Paris: Fayard, 1982.

I would also like to mention three books by Morin. One is autobiographical ("*Mes démons*"), another deals with the important issue of preserving the environment and the relations with complexity ("*Terre-patrie*") and the third one is a result of the sensitivity and intelligence of the author, expressed in three lectures ("Love, poetry and wisdom"):

MORIN, E. **Mes démons**. Coll. Au vif. Paris: Stock, 1994.

MORIN, E., KERN, A. B. **Terre-patrie**. Paris: Le Seuil, 1993.

MORIN, E. **Amour, Poésie, Sagesse**. Paris: Seuil, 1997. 81 p.

The other author who allows entering the complexity through the door of epistemology is Humberto Maturana, a Chilean biologist. Advocate of a non-representationalist view of cognition, Maturana, together with his old student, and not less famous than him, Francisco Varela, wrote a book ("The Tree of Knowledge") excellent in the sense of presenting the issue of cognition in a new epistemological way. Concepts such as structure

and organization play a central role in the vision of these authors, as well as autopoiesis (self-production). This latter concept has been used by some authors working in education, particularly to address the self-training in educational processes. The other two books mentioned unite several texts by Maturana, especially the ones on autopoiesis, on learning process, language and cognition:

MATURANA, H., VARELA, F. J. **The tree of knowledge: the biological roots of human understanding.** Boston MA: Shambhala, 1987.

MATURANA, H., VARELA, F. **Autopoiesis and cognition: the realization of the living**. Boston Studies in the Philosophy of Science. Paperback, 1991.

MATURANA, H. **Desde la biologia a la psicologia**. Paperback, 2004.

Another entrance to the complexity is by the cognitive sciences. In this direction is significant the contribution of Francisco Varela. This Chilean biologist was a prodigious mind. His contributions have collaborated to open ways in the renewal of the cognitive sciences ("*Autonomy and Knowledge*", "*The Embodied Mind*") with works published in Biology, but also in researches where he has interacted with physicists. In cognitive sciences Varela proposed a new dimension, beyond the cognitivist and connectionist: the enacting or unveiling alternative, which one is not representationalist ("*Invitation aux sciences Cognitives*"). This view of cognition replaces the question of forms of human organization from a creative, historical, body centered, and context sensitive perspective with important consequences, particularly for education. In recent years the cognitive science of Francisco Varela was approaching the idea of a *Husserlian* naturalized *phenomenology*, i.e., Varela was looking for an approximation of Husserl´s ideas to those of natural science ("*Naturalizing phenomenology*"). and Part of the Varela's legacy, the concerns also include, in an audacious exploratory mainframe, the dialogue between the Western thinking and the Oriental educational traditions represented by Buddhism, Taoism and Confucianism and, from this perspective, the biologist produced reflections on ethics ("*About the ethical competence* "):

VARELA, F., THOMPSON, E., ROSCH, E. **The embodied mind: cognitive science and human experience.** Cambridge: MIT press, 1991.

VARELA, F. J. **Invitation aux sciences cognitives.** Paris: Seuil, 1996. 125p. (From English: **Cognitive science: a cartography of current ideas**, 1988).

VARELA, F., **Principles of biological autonomy**. New York: Elsevier/North-Holland,

1979. 306 p.

VARELA, F. **Sobre a competência ética**. Lisboa: Edições 70, 1992. 104p.

PETITOT, J., VARELA, F., PACHOUD, B., ROY, J-M. (Org.) **Naturalizing phenomenology: issues of contemporary phenomenology and cognitive sciences**. Stanford: Stanford University Press, 1999.

Two cyberneticists of first time, the Austrian physicist Heinz von Foerster and the American anthropologist and ethologist Gregory Bateson, should be included in this bibliography. Von Foerster's contributions mainly concern ideas of self-organization, which he related to important problems in the emerging cognitive science (we are talking about the late forties and early fifties). For this physicist born in 1911, questions about the nature of life and the nature of cognition are intertwined. For him, the problem consists in explaining the activity of a living being in an uncertain environment and not an explanation of a finalized behavior (the organism studied by physiology). Bateson proposed himself to establish an epistemology of the living being. His researches are placed as a search by retracing what differentiates the living beings' diverse levels of organization and to analyze the properties that characterize the mental systems, which allow in classifying them, in short, find out how the complexity of the structure and complexity of functions reflect on one another. Bateson was also the one who introduced the idea of feedback in the social sciences and was the creator of the *Double Bind Theory* as a subsidy to explain schizophrenia. Bateson and von Foerster have, in this bibliographical perspective, not only a historic role, but also the one of had provided extremely powerful and original contributions, whose consequences have not yet been fully explored:

VON FOERSTER, H. **Observing systems** (VARELA, F. Ed.) Seaside, Ca: Intersystems, 1981.

BATESON, G. **Steps to an ecology of mind: collected essays in anthropology, psychiatry, evolution, and epistemology**. University Of Chicago Press, 1972.

Another entrance to the complexist traveler is through two authors already cited in this text. One is Ilya Prigogine, chemist and physicist born in Russia, with subsequent Belgian citizenship, and laureate with the Nobel Prize in Chemistry in 1977. Prigogine is a brilliant researcher, but also an excellent writer which allows in disseminating his ideas to the general public. His books to disclose ("*The new alliance*," "*Between Time and Eternity*",

"*Order out of Chaos*") are extremely encouraging but, despite including scientifically correct content, brings the danger of possible immediate generalizations by readers who are not specialists. In fact, there have been hasty readings of some of the Prigogine statements, mainly by researchers from the Human Sciences, leading to generalizations that are not always correct. However, the readers who have basic training in natural sciences are able to optimize the use of the Prigoginean writings. Besides these books directed to the general public, I included another ("*Exploring Complexity*"), more technical, written in collaboration with Nicolis Prigogine, readable by professionals and natural sciences students, since it uses elementary mathematics:

PRIGOGINE, I., STENGERS, I. **La nouvelle alliance: metamorphose de la science.** Paris: Gallimard, 1979.

PRIGOGINE, I., STENGERS, I. **Entre le temps et l'éternité.** Paris: Fayard, 1988.

PRIGOGINE, I., STENGERS, I. **Order out of chaos: man's new dialogue with nature.** New York: Bantam, 1984.

NICOLIS, G., PRIGOGINE, I. **Exploring complexity.** New York: W. H. Freeman, 1989. 313p.

Another author, quoted in this text, connected with issues of self-organization and noise, is Henri Atlan. This doctor, an intellectual that is noticeably original in their proposals, speaks from the biomedical sciences, but with an approach from a great extent connected with concepts of Information and Communication Theory. In addition, his themes and interests are broader, including education, psychology and philosophy, particularly ethics. The three books I suggests here are not very technical and easy to read. One of them ("*Between Crystal and Smoke*"), is the most known book of the author:

ATLAN, H. **Entre le cristal et la fumée: essai sur l'organisation du vivant.** Paris: Seuil, 1979.

ATLAN, H. **Com razão ou sem ela: intercrítica da ciência e do mito.** Lisboa: Instituto Piaget, s. d. (Tradução: Fátima Leal Gaspar e Carlos Gaspar). 397p.

ATLAN, H. **Tout, non, peut-être: education et vérité**. Paris: Seuil, 1991.

However, there are travelers for whom the journeys through the so-called hard sciences like physics and chemistry are more challenging. For those I suggest routes where they

envision ascendant ways, but which ones are surmountable. Indeed, there is some mathematical difficulty in them, and especially a more specialized conceptual universe. These texts do not constitute scientific publications. They must be read by the ones who are interested in to go deep in the natural science approach devoting a significant time. One of these books, cited before, is "*Exploring Complexity*" written by Nicolis and Ilya Prigogine. There is an excellent monograph written by Luzzi and Vasconcellos ("*Some considerations about complexity, self-organization and information*") in which one can be found, beyond very relevant content for the complexity in physics and chemistry, many references and suggested readings, including references in other areas of knowledge. Another text, a small and valuable one written by the physicist and Nobel Prize laureate P.W.Anderson ("*Is Complexity physics? Is it science? What is it?*), may help in clarifying the ideas of complexity in the hard sciences. Another suggestion, also very technical, is the book of the German physicist Haken, presenting his very important and elegant contributions, which resulted in the construction of a theoretical apparatus applicable to complex processes in physics, chemistry and biology:

LUZZI, R., VASCONCELOS, A. **Algumas considerações sobre complexidade, auto-organização e informação.** Campinas: Instituto de Física Gleb Wataghin, 1999. 164 p.

ANDERSON, P. W. "Is complexity physics? Is it science? What is it?" In **Physics Today**, July, 1991.

HAKEN, H. **Synergetics: nonequilibrium phase transition and self-organization in physics, chemistry and biology.** Berlin: Springer, 1978.

Generalizing, there are two ways by which we seek out to characterize complexity in the hard sciences. One is through the construction of systemic measure for complexity. For those who engage in this instance, the goal is to define an effective measure of complexity of an object, process, or system, without knowing its organizational and functional details. The complexity is identified as missing information, necessary to obtain a full explanation of the formation of the system and of the way it works. Two studies may introduce the reader in this universe. A first one, more recent and less technical ("*Systemic Measures and Organization*"), may work as an introduction to the approach. A second one, more technical ("*Measures of Complexity*"), should be read by those who wish to go deep in the subject:

PESSOA JR., O. Medidas sistêmicas e organização. In: Debrun, M., Gonzáles, M. E. Q., PESSOA JR. (Eds). **Auto-organização.** Coleção CLE 18. Campinas: Editora da Unicamp,

1996. Cap. 6, p. 129-161.

PELITE, L., VULPIANI, A. (Eds). **Measures of Complexity.** Berlin: Springer-Verlag, 1988.

The other way by which we seek out to address complexity in hard sciences is through models. In this case, complexity is an intrinsic property independent of the wider or restricted knowledge an external observer might have of the system details. The complexity, in this instance, does not disappear when the functions of the system can be reconstructed from its parts. The goal is to define the necessary structural conditions to identify a system as a complex one. These different "definitions" are provided by "models" for complexity which in general, each one is applicable to specific situations and issues. The Deterministic Chaos Theory is one of those models. Other ones are the Prigogine's dissipative structures (which are explained in "*Exploring Complexity*"), population dynamics models, percolation models, and spin-glass models. The ideas of autopoiesis by Maturana and complexity from noise by Atlan, also fall into this category. The Deterministic Chaos Theory generally raises much interest. Moreover, Prigogine spent several years on this subject and, as a travel guide, I would not fail in to not indicate this route. There are good scientific publications for the Deterministic Chaos Theor, as the best-seller by the American journalist James Gleick ("Chaos: Making a New Science"), the book by the mathematical David Ruelle ("Chance and chaos ") and one of the physicist Pierre Bergé ("*Des rythmes au chaos"). The* book by Glass and Mackey ("*From clocks to chaos*") shows chaos applications in the biomedical sciences using a sophisticated mathematical and conceptual universe. For those who want to deepen the study of deterministic chaos using mathematical formalism, I recommended the book I wrote with Cintra do Prado ("*Chaos: An Introduction*"). The subject Deterministic Chaos is fascinating for at least three reasons: first of all, because it deeply modifies the previous conception that unpredictable behavior could not coexist with determinism; second, because the chaotic phenomena manifest themselves in different areas of knowledge and nature, and may be measured in the laboratory; thirdly, because it is an example of intertwining between mathematics' concepts and experiments. Moreover, the Deterministic Chaos Theory, as pointed out before, is one of the theories that supports the new complexity paradigm.

GLEICK, J. **Chaos : making a new science.** New York: Viking, 1987.

RUELLE, D. **Chance and chaos**. Princeton, N.J.: Princeton University Press, 1991.

BERGE, P. **Des rythmes au chaos.** Paris: O. Jacob, 1994.

GLASS, L., MACKEY, M. C. **From clocks to chaos: the rhythms of life.** New Jersey: Princeton University Press, 1988. 241p.

FLEDLER-FERRARA, N., PRADO, C. P. C. **Caos: uma introdução.** São Paulo: Edgar Blücher, 1994. 402p.

For the traveler who is interested in paths that goes outside the hard sciences' realm, I provide here suggestions of reading on economy ("*The economy to an evolving system*"), in ("*La cohérence du réel, evolution, coeur du savoir*") and literature ("*Chaos and order: complex dynamics in Literature and science*").

ANDERSON, P.W. et al. **The economy as an evolving system.** New York: Addison Wesley, 1988.

LASZLO, E. **La cohérence du réel, évolution, coeur du savoir.** Paris: Gauthier, 1985.

HAYLES, W.K. (Ed.). **Chaos and order: complex dynamics in literature and science.** Chicago: The University of Chicago Press, 1991. 308p.

Education is a privileged area for the construction of complex thinking, because the dynamic of educational processes is complex and its reality of the world where teachers and students are immersed.

Despite there is a strong intuition in this direction by those who work in education, it is also true that in classroom pedagogical action and in the selection and organization of educational content, manifested in *curricula* and in most textbooks available, everything is still far from reach the necessary changes to overcome the disciplinary fragmentation of knowledge as well as the practice of presenting the content based in a logic of strict causality, which restricts, and most often prevents retro-alimentations between content, procedures, approaches and between educators and students. However, it starts building theoretical frameworks in order to support pedagogical actions that take into account the complexity of the real and of the classroom. It must be admitted that, when speaking in paradigm shift, education is a crucial point. After all, where else, otherwise in the school, the foundations of this new thinking will begin to bear fruit. I selected some works on education using a complexist referential base:

GARCÍA, J. E. **Hacia una teoría alternativa sobre los contenidos escolares**. Sevilla: Díada, 1988.

ZABALA, A. **Enfoque globalizador y pensamiento complejo.** Barcelona: Graó, 1999.

FIEDLER-FERRARA, N., MATTOS, C. **Seleção e organização de conteúdos escolares: recortes na pandisciplinaridade**. In: Vianna, D. M. et al. (Org). Encontro de Pesquisa em Ensino de Física, VIIL 2002, Águas de Lindóia. São Paulo; Sociedade Brasileira de Física, 2002 (CD-ROM, arquivo: C081_2).

To conclude this bibliography, I look after the traveler now who prefers to stroll around the cities' streets, the squares, and the fields. It is not to affirm that he is a superficial traveler, rather, he is alert, his eyes are jumping between the specific and the general, among the flower's most microscopic pollen and the fragile light of the distant star, obscured by a huge mountain or by the savage scream of an angry driver. For this traveler I've selected a few books, written by several authors from different areas and which ones address several issues related to the complex thinking, configuring to an attentive reader, a polyphony of ideas:

Castro, G., Carvalho, E. A., Almeida, M. C. (Orgs.). **Ensaios de complexidade.** Porto Alegre: Sulina, 1998. 271p.

PENA-VEGA, A.; NASCIMENTO, E.P.(Orgs.) **O pensar complexo: Edgar Morin e a crise da modernidade** . Brasília: Garamond, 1999. 200p.

DEBRUN, M., GONZÁLES, M. E. Q., PESSOA JR. (Eds). **Auto-organização.** Coleção CLE 18. Campinas: Editora da Unicamp, 1996.

NUSSENZVEIG,H.M. (Org). **Complexidade e Caos.** Rio de Janeiro: Editora UFRJ/COPEA, 1999. 276p.

CARVALHO, E.A., ALMEIDA, M. C., COELHO, N. N.; FIEDLER-FERRARA, N.; MORIN, E. **Ética, solidariedade e complexidade**. São Paulo: Palas Athena, 1998. 77p.

GREBOGI, C., YORKE, J. A. **The impact of chaos on science and society**. Tokyo, New York, Paris: United Nations University Press, 1997. 401p.

FOGEL, A., LYRA, M. C. D. P., VALSINER, J. **Dynamics and indeterminism in developmental and social process.** Mahwah, New Jersey: Lawrence Erlbaum Associates Publishers, 1997. 283p.

Final considerations

I believe that complex thinking can be the seed of a paradigmatic change in science. Significant part of the science that is practiced nowadays does not correspond to our time's needs. It does not attend to it because it is suffocated by the excessive expertise that restricts creativity. It does not attend to it because it is governed by the perverse logic of the market. It does not attend to it because it is too far from reality; far from the complexity of the concrete. It does not attend to it because it has not focused enough in solving problems that could improve the living conditions of hundreds of millions of people living in poverty and abandon in the world. It does not attend to it because it is blind, in the hand of the powerful, because the major part of the scientists is ignoring the social problems and is fighting in the first place for self reputation and money for themselves and their projects, supporting, sometimes, what Maurício Tragtenberg defined as 'Academic Delinquency' or 'Betray of the Intellectual'. It does not attend to it because it disregards the serious environmental problems caused by an insane economic system.

The complex thinking, it is a fact, brings in its core new and powerful tools to confront the real world problems. There is, indeed, enthusiasm that this thinking can be more open to changes, to creativity, to the benefit of the doubts and uncertainties that could contribute to reducing the absurd selfishness and blindness of the powerful and their accomplices. It is certainly fascinating and stimulating to participate in a time of paradigmatic shift, after several centuries of Cartesian hegemony. Nevertheless, we are living a new situation. It is not a matter of replacing the reign of Cartesianism by the one of Complexity, but to intertwine harmoniously what we have learned from different cultures along the centuries. But what for? For delighting once again by our intelligence? To celebrate once again the supremacy of homo-sapiens in a universe whose boundaries in the macroscopic and microscopic are being extended? What will we do concerning the homo-demens inside each one of ourselves? We'll pretend it does not exist?

No. This time we need more than experts and skilled technicians. We need more then brilliant intellectuals. We also need to undertake a profound shift in our minds and our attitudes. This change ought to happen by the seriousness of the situation we are living in. It is in this direction we must work and educate the new generations. Our efforts must be towards the construction of a new paradigm – being this one the complex or any other one which will guide us through the historic-cultural process that collaborate to the happiness and harmony of the living beings in a relation of mutual love and love by the nature. However, we must be conscious that this historical-cultural process is produced by our actions. By this motive, we must be attentive to them and to our responsibility.

[1] It should be clear that these principles, though I particularly enjoy and use the method, they are not present in all complex formulations. They relate to the specific contribution of Edgar Morin, not excluding contributions of predecessors and contemporaries. It is noted that Morin, through his monumental work "Method" (see suggested reading at the end of text), is a crucial reference in the area. [back to the text]

[2] Translator's note: Book references indicated by the author in Portuguese were substituted by international editions, in the case it exists, in order to make easier to the reader to find them. [back to the text]