The need for the historical understanding of nature in physics and chemistry

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THE NEED FOR THE HISTORICAL UNDERSTANDING OF NATURE IN PHYSICS AND CHEMISTRY

ABSTRACT. During the last decades the physico-chemical conception of self-organization of chemical systems has been created. The chemical systems in natural-historical processes do not have any creator: they rise up from irreversible processes by self-organization. The issue of self-organization in physics has led to a new interpretation of the laws of nature. As Ilya Prigogine has shown, they do not express certainties but possibilities and describe a world that must be understood in a *historical* way. In the new philosophical understanding of nature priority is not ascribed to any single *type* or *level* of entity, but to historical processes, to processes of endless generation and change.

1. INTRODUCTION

My paper will focus on the problem of cooperation between the human and physical understanding of the world. Up to the last decades the dualistic world-view formed by Plato and Democritus and influenced by the Cartesian/Newtonian mindset has dominated. The human (internal) and the physical (external) world have been in conflict with each other. The human experience has been neglected in the west. Likewise Democritus who according to a legend blinded himself deliberately to get rid of "illusory" sensual experiences,

the present-day humankind has deliberately blinded itself intellectually in respect to the rich content of conscious experience, because from this content it is evident that the clear but primitive modern scientific world view, in which most of the educated people want to believe, is erroneous.

For the sake of the advancement of sciences it is high time to abandon the fallacious contemporary "scientific" world view (Uus, 2001, p. 122).

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During the last decades revolutionary changes have occurred in natural sciences, first of all, in physics and chemistry. The new phenomenon of self-organization has been discovered and philosophically interpreted (Earley, 1981, 1998, 2000, 2003a, b; Kauffman, 1993, 1995, 2000; Näpinen, 1982, 1983a, b, 1984, 1993, 2001a, b, 2002, 2003, 2004a, b; Näpinen and Müürsepp, 2002; Pechenkin, 1986, pp. 184–192; Salmon, 2003; Vihalemm, 1981, pp. 138–141; 2001; Vihalemm and Näpinen, 1986, 1987; Zwierlein, 1994; *etc.*). In the present article, I will consider the philosophical aspects of the new formulation of the laws of nature suggested by Ilya Prigogine (1917–2003) in a framework of the scientific paradigm of self-organization. I hope to argue whether this new kind of laws is consistent with the need to understand the world in a historical way.

2. THE CONCEPT OF SELF-ORGANIZATION

In this essay, the concept of self-organization is opposed to the concept of organization (Näpinen, 1982, 1983a, 1993). The concept of organization denotes a process that leads to the rise of goal-oriented structures due to conscious human goal-directed action, or due to some external *ordering* influence. As to the concept of self-organization, it denotes a process that leads to the rise of goal-oriented structures *without* conscious human goal-directed action, or any external *ordering* influence. True, external factors are indispensable for self-organization, but only as conditions, not as ordering forces.

Historically, the beginnings of the concept of self-organization may already be found in Aristotle's doctrine of causality. Aristotle's four kinds of causes – *material, formal, efficient*, and *final causes* – I interpret, in their inseparable unity, as a philosophical concept of self-organization (embracing both the process without an *external* organizer, and its result). The first three kinds of causes I interpret as a philosophical concept of organization (involving an *external* organizer, the process and its result). The essential characteristic of a self-organizing system is its *autonomous* purposive behaviour. The characteristics of a self-organizing system cannot be constructed according to an *external* purpose. I note here that my understanding of the concept of self-organization and organization is close to Rein Vihalemm's view (Vihalemm, 1981, pp. 138–141; 2001). It must be stressed that theories, characterized as organization, are "dealing with the typical impact of the non-Aristotelian effective cause (instead of Aristotle's third cause) that realizes the external purpose, while Aristotle's natural final cause is ignored" (Vihalemm, 2001, p. 194).

Referring twice to the same paper (Näpinen, 1983a, pp. 103–104), a Russian philosopher Georgij I. Ruzavin (1984, p. 42; 1985, p. 53) described the situation in the understanding of organization and self-organization in the following way.

Usually the nature of organization is understood as a certain order of the elements of a system that makes it possible to achieve some integral result. However, in such understanding there is often tacit agreement that the organization is carried into effect thanks to conscious human efforts. That is why the concept of organization is used to express the rise of harmonious functioning in a system when harmony is determined by an external ordering influence. In synergetics (an another name for the self-organization theories given by Hermann Haken) organization is understood analogically.

Self-organization, however, is understood in synergetics otherwise than in cybernetics and systems engineering. In the two last disciplines self-organization is understood as an effect of an external *ordering* factor. Systems in cybernetics and in systems engineering have the external purpose. In synergetics self-organization is understood as the rise of harmonious behaviour distinguished from man's intervention and from external (with regard to the system) ordering factors. External factors (e.g., strong non-equilibrium) function only as conditions, not as ordering forces. Self-organizing systems in synergetics have their own (i.e. autonomous) goals (in the meaning of Aristotle's natural final cause).

It was interesting for me to learn that Hermann Haken (1978, Ch. 7) interprets the concepts of organization and self-organization analogically to the philosophical definitions that I have suggested. This analogy lies in the fact that Haken takes into account the inseparable unity of the process and its result, and also the origin of the determinants of the functioning or behaviour of the system. The concept of organization expresses the situation in which the determinants of the process come from outside and the process itself leads to the formation of goal-directed structures. The concept of self-organization expresses an analogous situation with the difference that the determinants of the process are not forces but integral regularities (*long-range correlations*) and they emanate from inside the system. From the philosophical point of view it must be stressed that in experimental situations the determinants of the organization are contingent on the subject (the experimenter).

The philosophical concepts (categories) of organization and self-organization were used (Näpinen, 1982, 1983a, b, 1984, 1993) for the detection of essential changes (revolution by Prigogine) in exact sciences.

3. TWO CONCEPTUAL SYSTEMS IN CONTEMPORARY MATHEMATICAL NATURAL SCIENCE

It became evident that for studying the *processes* there exist two conceptual systems in contemporary mathematical natural science: *the theories of organization* (cybernetics developed by Norbert Wiener, William Ross Ashby and others, the kinetic theories in chemistry, including the theory of evolution of open catalytic systems developed by Alexandr P. Rudenko (1969, 1983), and some other theories) and *the theories of self-organization* (non-linear non-equilibrium thermodynamics developed by Ilya Prigogine and his collaborators, the theory of self-organization of biological macromolecules developed by Manfred Eigen, the synergetic method of Hermann Haken, and some other theories). The former are expressed by the category of organization, the latter by the category of self-organization. All the theories of self-organization represent a certain integral *orientation* in contemporary mathematical natural science, i.e. synergetics. The main difference between the theories of organization and those of self-organization is the fact that the former are based on the methods of *constructing*, but the latter start from the already existing, from what is given in the historical reality. The theories of self-organization form a new conceptual system (i.e. a conceptual system in the sense of Werner Heisenberg (1958, Ch. 6), who distinguished five closed systems of physical concepts) that originates from the works of Ilya Prigogine and his collaborators on non-linear non-equilibrium thermodynamics. The rise of a new conceptual system is connected with the circumstance that theories, characterized by the category of self-organization, were the first among exact sciences to use the evolutionary models and modes of thinking from biology.

As to the development of chemistry, there exist four conceptual systems: theories of chemical composition, chemical structure, chemical kinetics (characterized by the category of organization), and chemical self-organization (Vihalemm, 1981, pp. 138–141; 2001, pp. 193–195). The idea of the conceptual systems of chemistry was introduced by Kuznetsov and Pechenkin (1971) and Kuznetsov (1973). Rein Vihalemm (1981, p. 139; 2001, p. 193) modified the general scheme of Kuznetsov and Pechenkin.

4. A NEW TYPE OF LAWS IN PRIGOGINE'S PARADIGM OF SELF-ORGANIZATION

The fundamental assumption of Prigogine's approach to nature is that *all* the real processes of nature are irreversible (as we experience in our every-day situations). These are the irreversible natural processes that make the self-organization possible. Namely the concept of self-organization lies at the centre of a larger theoretical revolution in physics – the belief that the fundamental laws of nature do not express certainties but possibilities and

> describe a world which demands to be understood in a *historical* manner. *The physics of the laws* thus *opens itself in a coherent way to the notions of events and novelty without which what we call nature would be incomprehensible* (Prigogine, 1998, p. 2; *emphasis* added).

The main figure among scientists representing this belief has been Ilya Prigogine (Prigogine, 1980, 1983, 1997, 1998, 1999–2001, 2000, 2003; Prigogine and Stengers, 1977, 1984; Kondepudi and Prigogine, 1998), who worked on non-linear, non-equilibrium thermodynamics of chemical reactions and, in particular, on *dissipative structures*. To Prigogine, irreversibility is a fundamental property of physical systems. In a new microscopic equation, Prigogine (1980) combined the reversible and irreversible aspects of physical evolution. In the last decades Prigogine's main interest was concentrated on *large Poincaré systems* (see, e.g., Prigogine, 1997; Bishop, 2003) that he identified with probabilistic imaginations irreducible to detached trajectories (belonging to classical mechanics) or detached wave functions (belonging to quantum mechanics). Prigogine (1997) became convinced "that the certainty of the deterministic, time-symmetric trajectory description is not applicable to the global dynamics of a large Poincaré system" (Bishop, 2003, p. 19). In Newtonian paradigm, "particle positions and trajectories are treated as the fundamental *ontological* entities determining the dynamical evolution of the system" (Bishop, 2003, p. 19; *emphasis* added). In contrast, in Prigogine's paradigm, the fundamental *ontological* feature for large Poincaré systems "are the probability distributions, i.e., the large-scale arrangements of the particles themselves" (Bishop, 2003, p. 19). Large Poincaré systems Prigogine treated as wholes. The new laws of nature (the so-called laws of chaos) in Prigogine's formulation "deal with the possibility of events, but do not reduce these events to deductible, predictable consequences" (Prigogine, 1997, p. 189).

Prigogine has repeatedly emphasized the constructive role of irreversibility: self-organization results from irreversible processes. Because all complex systems undergo irreversible processes over time, the temporal direction from past through present to the future is called *arrow of time*. (Arthur Eddington, as we know, first used this term. In my view, many authors (e.g., Price, 1996; Zeh, 2001) who use this term do not pay enough attention (especially in the philosophical sense) to the work of Prigogine's school on irreversibility. Moreover, in some publications (e.g., Savitt, 1996) about the direction of time Prigogine has completely been ignored.) Prigogine has written:

> ... Irreversibility can no longer be identified with a mere appearance that would disappear if we had perfect knowledge. Instead, it leads to coherence, to effects that encompass billions and billions of particles. ... We are actually the children of the arrow of time, of evolution, not its progenitors (Prigogine, 1997, p. 3).

Prigogine has defined self-organization as "The choice between solutions appearing at a bifurcation point, determined by probabilistic laws. Far-from-equilibrium self-organization leads to increased complexity" (Prigogine, 1997, p. 205).

Prigogine has said that,

> In general, ... there are successions of bifurcations, introducing a "historical" element. It is now generally well understood that all structures around us are the specific outcomes of such historical processes. The simplest example is the behaviour of chemical reactions in far-from-equilibrium systems (Prigogine, 2000, p. 894).

Prigogine (1980) postulated the second law of thermodynamics as a fundamental theoretical fact, as a principle of selection leading to the breaking of time symmetry. He treated the breaking of time symmetry as an *inner* quality, meaning that the treatment of time as an *operator* can make it possible to explain the inner (not depending from new interactions) breaking of time symmetry *simultaneously in mechanics, quantum physics and relativity theories*. In Prigogine's interpretation, the second law of thermodynamics does not express the practical improbability of one or another process (as in Ludwig Boltzmann's interpretation) but the choice between states which are allowed. As said in the language of physicists, only states are allowed which break time symmetry. Any kind of probabilistic interpretation becomes possible only after time symmetry is broken.

The traditional interpretation of the second law of thermodynamics states that things, if left to themselves, tend towards increased entropy. In the 1960s, Ilya Prigogine and his followers realized that in the real world particles (atoms and molecules) are almost never "left to themselves". Everything affects everything else. Effects in real situations include the breaking of time symmetry, diffusion and non-local correlations. Prigogine and co-workers considered these effects as "non-Newtonian" because distribution descriptions incorporated by them cannot be reduced to point-wise (i.e. trajectory) descriptions (Bishop, 2003, p. 17). (It must be noted here "that singular distributions such as delta functions *are not* used to represent probability distributions in the rigged Hilbert space approach" (Bishop, 2003, p. 7, note 5), i.e. in Prigogine's and his co-workers' approach).

To evaluate the approach of Prigogine in an appropriate way, it is very important to make a clear distinction between the *deterministic chaos* and the *quantum chaos* (see Näpinen and Müürsepp, 2002). For considering the quantum chaos we must take into account the main differences between Newton's laws and quantum mechanics. If Newton's laws are entirely deterministic, then quantum rules have a probabilistic character. Because of these and other differences one cannot define chaos in quantum mechanics in the same way it is defined in Newtonian mechanics. Deterministic chaos is defined by the ideas of sensitive dependence on initial conditions and exponentially diverging trajectories. The Heisenberg uncertainty principle makes it unjustifiable to talk about initial conditions and trajectories in quantum mechanics. There are some alternative attempts to define quantum chaos in the scientific literature (the theory of *decoherence* (see, e.g., Decoherence ...), definition by the concept of the collections of a very large number of trajectories, definitions by means of different statistical properties of the eigenvalues of chaotic and regular quantum systems, *etc*.).

Ilya Prigogine (1997, pp. 53–54, 204) connects the concept of quantum chaos with *Poincaré resonances* – "Coupling of degrees of freedom that lead to divergent expressions due to small denominators if there is resonance between them. The resonances may prohibit the solution of the equations of motion". Robert Bishop explains:

> Poincaré showed that systems of equations were nonintegrable when they contained *resonances* between various degrees of freedom. In essence a resonance is a transient metastable state establishing a narrow, precise frequency gateway through which energy can be efficiently transferred from one element of a physical system to another. Physical examples of

resonances include transient bound states produced in particle collisions and transient intermediates in chemical reactions'' (Bishop, 2003, p. 3).

Poincaré resonances destroy the *dynamical group* (in *Hilbert space*) in which the past and future play the same role and make it possible to obtain *semigroups* of operators (outside Hilbert space – in Gel'fand space that can be considered as rigged Hilbert space, or in rigging ''Liouville space'' (see, e.g., Bishop, 2003)) breaking time symmetry. Bishop writes:

The rigged Hilbert space ... approach of the Prigogine school is a method for solving the equations of a large Poincaré system (both classical mechanics and quantum mechanics) consisting in constructing a complete set of eigenvalues and eigenvectors for the Liouville operator acting on distribution functions ...'' (Bishop, 2003, p. 6; author's abbreviations have replaced by the full terms).

A selection of ''the physically relevant semigroup of evolution operators for modelling statistical mechanical systems'' Prigogine takes ''to be an expression of the second law of thermodynamics based on our empirical observations'' (Bishop, 2003, p. 11). Poincaré resonances are also the reasons why one has to consider the systems as consisting of particles in *persistent* (not in transient) interaction. Incessant interaction leads to diffusion-type processes that correspond to irreversibility (see, e.g., Prigogine, 1997, Chaps. 5–7). As in extended (i.e. grasping the thermodynamic situations) classical mechanics, in extended quantum mechanics ''Poincaré resonances introduce new dynamical events that couple the creation and destruction of correlations, and therefore describe quantum diffusive processes'' (Prigogine, 1997, p. 148). All dynamical (mechanical and quantum) systems with an incalculable (*infinite*) number of particles in *incessant* interaction Prigogine, following Henri Poincaré, calls *nonintegrable* systems. In *integrable* systems interaction can only be temporary: it can be eliminated. Continuous resonances are involved in absorption and emission of light, in decay of unstable particles, and in some other fundamental phenomena (Bishop, 2003, p. 6). Prigogine (2003) considered chemistry as belonging to the class of nonintegrable (i.e. with particles in *incessant* interaction) Poincaré systems.

Deterministic chaos models systems with a *finite* number of elements (or degrees of freedom). Quantum chaos models systems with an *infinite* number of elements (according to conditions of the so-called *thermodynamic limit*: the volume and the number of particles tend to infinity, but the ratio of their number to the volume remains finite and constant). Deterministic chaos is rooted in the precision of initial conditions, i.e., in the problem of measurement. Quantum chaos is the property of quantum *large Poincaré systems* (with continuous energy spectrum "due to Poincaré resonances taken in the thermodynamic limit" (Prigogine, 1997, p. 203)) and manifests through the decay of quantum correlations in time. If we take into account quantum chaos, we cannot even in principle accept that the world is (pre)determined, as it was supposed by classical exact science. If deterministic chaotic systems (i.e. *finite* systems) are described by connected equations so that the variables are in correlation with each other, then in *infinite* non-equilibrium quantum systems, there is an *infinite* number of parts correlated with each other and because of that the phenomena emerging in *infinite* quantum systems cannot be described by a mathematical apparatus (e.g., Hilbert space, and time as an external *parameter*) which is still being used (e.g., Price, 1996; Zeh, 2001) for describing dynamical systems. Prigogine and co-workers developed their approach outside Hilbert space and tried to explain the thermodynamic arrow by the mechanisms of diffusion, the growth of correlations and collective effects (Bishop, 2003, pp. 11, 12). (The collective effect is "the behaviour of an aggregate of particles coupled together in some fashion that is distinct from the behaviour of individual particles" (Bishop, 2003, p. 12).) All of these mechanisms Prigogine with co-workers considered as results of Poincaré resonances.

True, both deterministic chaos and quantum chaos are just models, mathematical abstractions. Both are relevant in their own application limits. For example, for physical-mathematical modelling the Belousov–Zhabotinsky reaction the researchers are justified to use both the concept of deterministic chaos and the concept of quantum chaos. For explaining the emergence of closure of coherent sets of processes the concept of quantum chaos applies, for calculating the changes in concentrations of chemicals the concept of deterministic chaos fits. (The model *oregonator*, for instance, is a completely determined system of differential equations.) However, the world as a whole and the other wholes with autonomous purposes produced by the former must be interpreted as being based on the fundamental indeterminacy.

5. A HISTORICAL UNDERSTANDING OF NATURE

As already indicated above, Prigogine declared that his new formulation of the fundamental laws of nature describes a world that demands to be understood in a historical manner. What does this mean? For getting an answer let us turn to biological sciences (because in their essence they are the historical sciences). Stephen Jay Gould (1941–2002), one of the best-known and widely read scientists of the late 20th century, has pointed out

> two ends of a primary dichotomy about the nature of history ... – the twin requirements of uniqueness to mark moments of time as distinctive, and lawfulness to establish a basis for intelligibility.
>
> At one end of the dichotomy – I shall call it time's arrow – history is an irreversible sequence of unrepeatable events. ... (Gould, 1987, p. 10).

Time's arrow Gould has explained in the following way:

> Time's arrow expresses the profundity in a style of explanation that many people find disappointing, or maximally unenlightening – the argument that "just history" underlies this or that phenomenon (not a law of nature, or some principle of timeless immanence). *The essence of time's arrow lies in the irreversibility of history*, and the unrepeatable uniqueness of each step in a sequence of events linked through time in physical connection – ancestral age to modern human, sediments of an old ocean basin to rocks of a later continent. Abstracted parts of any totality may record the predictable (and repeatable) operation of nature's laws, but the details of an entire configuration are "just history" in the sense that they cannot arise again, and that another set of antecedents would have yielded a different outcome (Gould, 1987, p. 194; *emphasis* added).

Gould gave the next definition of the historical character of life:

> To understand the events and generalities of life's pathway, we must go beyond principles of evolutionary theory to a paleontological examination of the contingent pattern of life's history on our planet – the single actualized version among millions of plausible alternatives that happened not to occur. Such a view of life's history is highly contrary both to conventional deterministic models of Western science and to the deepest social traditions and psychological hopes of Western cultures for a history culminating in humans as life's highest expression and intended planetary steward (Gould, 1994, p. 84; quoted from Prigogine, 1997, pp. 161–162).

Gould has stated that evolution cannot be equated with progress; he has emphasized *historical contingency*. Or, as Prigogine (1997, p. 161) noticed, "there exists a multiplicity of evolutions, which are particularly evident in the field of biology. ... It would therefore be a mistake to consider a simple one-dimensional evolution".

Therefore, the specific feature of the historical cognition is first of all linked with the mental *re*constructing of the irreversible process in historical time. The characterization of the historical phenomena is not possible without any knowledge on their past, their emergence in the process of irreversible evolution. The results and conditions of qualitative leaps in historical process cannot be predetermined, because the future of historical phenomena is not inherent in the present. A 'physical-mathematical' science, however, is searching for laws (deterministic or probabilistic) and because of that it cannot in principle grasp the *historicity* of phenomena; it can only be used in the modelling of some aspects of historical phenomena already reconstructed by historical cognition. The historical approach is based on analogies and deals with the classification and qualitative description of phenomena. Large Poincaré systems are mathematical abstractions functioning at the thermodynamic limit. They are these abstracted parts of the physical world that, in the words of Gould, "record the predictable ... operation of nature's laws".

We can conclude that Prigogine's approach is actually a cooperative enterprise: the understanding of the irreversible, self-organizing and historical processes comes from outside the 'physical-mathematical' part of Prigogine's theories. The laws in Prigogine's formulation are used for modelling the processes that are already somehow understood – by common sense, philosophy and historical research. Therefore in the context of the new 'physical-mathematical' science (that, using Rein Vihalemm's term, remains a ϕ-*science* (see, e.g., Vihalemm, 1995, 1999, 2001)) it is justified to speak on the *element* or *aspect* of history, but not on history in its full sense. The Prigogine's conceptual scheme brings into physics the "narrative" element (cf. Kauffman, 2000) that so far worked only in historical sciences. As for the problem of the origin of life, it must be stressed that Prigogine (2004) has sincerely admitted that no evolutionary mechanisms that will support the origin of life have yet been discovered.

Prigogine's theories, for the first time in the history of *exact* sciences, are *not* grounded on the idealization of reversibility of fundamental processes. On the contrary, they are based on the real irreversibility. It is exactly this what makes it possible to take explicitly into account the *history* of systems and their *self-organization*.

5.1. Towards a historical understanding of chemical systems

Biology is first and foremost a historical discipline, although partially it also makes use of hypothetical-deductive theories, which are based on human constructive activity. Physics during the last three centuries has first and foremost been a science of laws. I believe that chemistry, linking biology and physics and still having its own specific character, can remarkably contribute to the historical understanding of the world.

Joseph E. Earley has written: "... In many branches of present-day science (including many parts of chemistry (Lehn, 2001)) questions of evolutionary development (history, in a sense) are of central importance (Mason, 1991) ..." (Earley, 2004, p. 11; this and the next passages are quoted from the version of paper accepted for publication in *Foundations of Chemistry* and kindly given me by the author). And specially about chemical systems:

... Many of the most important and interesting stages in the evolutionary epic are deeply chemical in nature (Mason, 1991) – fusion of hydrogen to helium in stars, cooking of heavy elements in supernovae, coalescence of inorganic compounds to produce cosmic dust and eventually planets, segregation of Earth's core and mantle, geochemical cycles, origin of life (Earley, 1998), initiation of photosynthesis, symbiosis of simple organisms and eventual formation of multicellular life-forms – all of these processes can profitably be approached from the chemical point of view. ... (Earley, 2004, pp. 13–14).

Earley added:

Most of the existing areas of present-day science, including much of chemistry, involve a mainly *synthetic* approach rather than a primarily *analytical* one. The old story-line of introductory chemistry courses – 'whatever exists can be understood through *analysis* into its component parts' – is no longer sufficient. A more appropriate story-line would be – 'everything came to be through *synthetic* processes' – that is the Evolutionary Epic. ... (Earley, 2004, p. 14).

6. CONCLUSION

My concluding remarks of this short overview are as follows.

The new natural science through a new formulation of nature's laws recognizes creativity, which is based on chance (randomness) and irreversibility of nature and, ultimately, acknowledges the fundamental indeterminacy of the whole history of nature and human society. Prigogine's new dynamic description requires decisive abandonment of the level of fundamental description, which is not supposed to depend on the scientist. The scientist himself and his activity, including its products, can from now on, be treated as belonging to nature. I am in complete agreement with following words of Joseph E. Earley:

A conceptual scheme based on single, material "particles" as fundamental constituents of physical things – on a single ultimate level of explanation to which all other levels of explanation were related as approximations – is no longer adequate. In the new 'idea of nature' priority is not ascribed to any single *type or level* of entity – be it microscopic corpuscle, individual biological organism, or self-determining human agent. What *is* fundamental are the (historical) processes by which individual entities are integrated into functional unitary aggregations. Humans are no longer regarded as somehow *apart from* the natural world, but rather are seen as *parts* of nature (Kauffman, 2000), comprised of myriads of smaller systems, and also components of large-scale natural aggregations – including familial, political, economic, linguistic, cultural, and ecological systems. Even though many (perhaps most) working scientists still hold doctrines that were dominant in their formative years, mainstream philosophical opinion no longer holds that science is different in kind from other human intellectual pursuits – the myth of 'the scientific method' has been superseded (Harré, 2000). Introductory instruction in science should no longer be carried out as if in relative isolation from other human concerns (Earley, 2004, p. 12; author's *emphasis*).

Therefore, we can conclude that beyond the separation of human (internal) and physical (external) worlds goes the actual need for a historical understanding of only one, self-organizing and evolving world, where also humans belong to and what among its multiple historical pathways involves the physical and chemical stages of development. For searching this understanding it is very important to realize that "it is definitely impossible that our understanding will ever be neutral or objective or complete" (Zwierlein, 1994, p. 294).

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