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NATURAL SCIENCES: DEFINITIONS AND ATTEMPT AT CLASSIFICATION

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ABSTRACT: The article discusses the formal classification of natural sciences, which is based on several propositions: (a) natural sciences can be separated onto independent and dependent sciences based on the gnosiologic criterion and irreducibility criteria (principal and technical); (b) there are four independent sciences which form a hierarchy: physics ← chemistry ← terrestrial biology ← human psychology; (c) every independent science except for physics has already developed or will develop in the future a set of final paradigms formulated in the terms of the science one step above it in the hierarchy; (d) some paradigms in physics will never become final; (e) each independent natural science has dependent sciences with paradigms already expressed in the terms of the respective independent sciences. Existing paradigms of independent natural sciences are listed and discussed with respect to the degree of their approach to the final state.

KEYWORDS: Natural Sciences; classification

1. INTRODUCTION

The goal of this article is to provide a formal classification of natural sciences. A necessary prerequisite for this attempt is a brief exposition of definitions related to natural sciences. The principal philosophical basis of this presentation is pragmaticism as proposed by C. S. Peirce (1878). Some of the ideas used in the text were formulated long ago in the early works of K. Popper (1934) and T. Kuhn (1962); these ideas are well known; referencing and describing them would be superfluous. In general, this text can be viewed as an affirmation and elaboration of the reductionism principle in describing natural sciences, in opposition to several authors in the field of natural philosophy, notably N. Cartwright (1989, 1999) and J. Dupré (1993, 2003).

Before the principles of science classification are discussed, two points must be made clear:

(a) The proposed classification completely ignores the history of natural sciences. We call "a natural science" a particular field of knowledge as we know it now and what we can anticipate to learn in the foreseeable future. The reason for this neglect of historicity is discussed in the final section of the paper.

(b) The classification of natural sciences, as any other classification, is not by itself an especially exciting subject. The reader should not expect to find new sweeping scientific ideas here. Moreover, any attempt at classification of sciences suffers from inevitable obviousness of many statements (for which this author apologizes). Rather, classification of natural sciences is useful by providing a single framework for placing any current or future scientific finding or a theory within a common context.

The author finds convenient to discuss the subjects related to classification of natural sciences in the terms of four categories of statements:

1. Definition: a linguistic statement defining a particular subject.
2. Proposition: a statement representing one of the bases of a given theory.
3. Lemma: a simple proposition that does not require a proof for obviousness.
4. Conjecture: an intuitively appealing but not an obvious statement that does not have a proof yet.

This approach inevitably leads to a certain level of didactic exposition, a manner which may irritate some readers but appears to be the most suitable for the task at hand.

2. PROPOSITIONS AND DEFINITIONS

Proposition 1: Within the present context, the term "natural science" describes the gnosiologic construct. A natural science is a category of human intellectual activity which has two goals: (a) the development of models (theories) about the nature of particular natural phenomena or objects, and (b) testing these models by comparing their predictions vs. experimentally observable (accessible) features of the phenomena or the objects.

Definition 1. Natural sciences are the group of sciences dealing with the material word.

Proposition 2: **Scientific models**. A scientific model is a rule or a list of rules (preferably, precise quantitative rules) that describe a set of phenomena or the properties and the behavior of a set of objects. The term "model" reflects the temporary nature and fallibility of most models (see Proposition 3 and Conjecture 2 below) and the subjective nature of scientific models, which are merely intellectual constructs (P. Teller, 2008). One good example of the models' subjectivity is the statement of Hawking (2001) about extra dimensions in the string theory: "… the question 'Do extra dimensions really exist?' has no meaning. All one can ask is whether mathematical models with extra dimensions provide a good description of the Universe." In layman's terms, the goal of a scientific model is to provide exhaustive answers to all applicable questions of "how" and "why". An answer to a "how" question refers to the quantitative description of a phenomenon or an object. A model that achieves this goal is called an adequate model (the meaning of the term is elaborated below). Very few natural phenomena do not have adequate models yet; one such exception, for example, is a ball lightning. The answer to a "why" question is the subject of Conjecture 2.

Definition 2: **Adequate models**. An adequate model is a model that, at a particular point in time, consistently describes all essential features of given phenomena or properties of given objects in a non-contradictory and intellectually satisfactory manner. An adequate model has predictive power in one or several of three senses:

1. It predicts yet-unknown features of known phenomena or objects belonging to a given set.
2. It predicts the existence of new (not yet discovered) objects or phenomena within the set and predicts their principal features and properties.
3. It predicts impossibility of the existence of certain other objects or phenomena within the set.

The predictive power of most well-developed adequate models is phenomenal, both in the positive and the negative sense. School-text examples of some of long-lived models are the Newton law of gravity and the Periodic Table of chemical elements. (It should be kept in mind that both models have been superseded by more advanced models.) The Newton model adequately describes the flight of a spacecraft to a remote planet although the author of the model has never anticipated such an application. Mendeleyev not only predicted the existence of several not yet discovered chemical elements in his Periodic Table and correctly described their chemical properties; he also stated, correctly as well, that there are no gaps for other "yet undiscovered" elements within his series. The latter example also shows limitations of even well-established adequate models: noble gases are elements that were not anticipated in the original Mendeleyev model (they are not positioned within his series) but they are fully incorporated into the modern model of the Periodic Table of Elements.

Definition 3: Scientific experiments. A scientific experiment is an observation or a manipulation of an object or a phenomenon, which is based on the current model and has an implicit goal of confirming, expanding, and improving the model. Two necessary features of a valid scientific experiment are reproducibility and objectivity. Most scientific experiments, in the T. Kuhn's disparaging comment (1962), are puzzle-solving exercises. The definition of the first feature of a valid experiment is circular: only reproducible experiments are valid. Two recent examples: after the model of the stomach (duodenal) ulcer as an infectious bacterial disease was experimentally demonstrated for the first time, thousands of medical doctors carried out many thousands of "experiments" (treatment of ulcer sufferers with antibiotics) and the outcome of the original experiment was reproduced every time. On the other hand, the controversy over "cold fusion of atomic nuclei" experiments in physics is mostly fuelled by the fact that these experiments are not uniformly reproducible. If they were, a number of current models in the field of nuclear physics would fail or would be greatly modified (see Proposition 3 below).

The term "objectivity of a scientific experiment" is used here in a very narrow sense; it refers to repeatability and reproducibility of an experiment without any regard to subjective human theories and beliefs; compare to Galison and Daston (2007). Using the same example of duodenal ulcer: although some of its sufferers may adhere to the Chinese medical teaching or to the voodoo theory of human illnesses, if they are treated with a proper antibiotic, best of all, without their knowledge, the outcome of such "an experiment" will be uniformly reproducible as well.

The principal occupation of any experimental researcher in the field of any natural science, at least for the last two centuries, is systematic research. All systematic research is incremental; it is aimed at supporting and improving existing models developed by theoretical sciences (Definition 3). Systematic research is sometimes carried out on a grand scale (development of nuclear weapons and nuclear energy, a search for new elemental particles using large particle accelerators, the human genome project, the hadron collider, etc.) and it can produce outstanding practical results. However, incremental systematic research (the "puzzle-solving"), as a rule, does not change the underlying scientific models.

On rare occasions, such a research produces unexpected results, which are called discoveries. (Within this definition, for example, the confirmation of the Higgs boson's existence is not a discovery; the existence of the particle was predicted 50 years ago and its energy was estimated beforehand.) All discoveries occur either by accident or due to a mistake in the design of an experiment or its implementation. A discovery is defined as an outcome of a scientific experiment that (a) has not yet been predicted by the existing model, or (b) contradicts the model. Discoveries of the first type are, over time, incorporated into existing models by refining them. Quite often, general models for such discoveries have been already developed but were not used or were not appreciated for the lack of experimental data. Some of the most spectacular discoveries of the 20th century, such as superconductivity, superfluidity of liquid helium, semiconductors, lasers and masers, relic radiation from the Big Bang, synthetic polymers, antibiotics, etc., belong to this category of initially unanticipated discoveries which were rapidly and fully incorporated into existing models.

In a few exceptional cases, the result of an experiment utterly fails to conform to a particular model it was expected to support and it cannot be accommodated within the model even after best theoretical attempts. After the outcomes of such experiments are confirmed (usually repeatedly), they form the basis of a scientific revolution. For example, the Michelson-Morley experiment in 1887 was designed as a typical systematic research to measure the speed of the Earth movement through the cosmic ether. The final outcome of this modest low-cost experiment was the creation of the special relativity theory. M. Planck carried out the blackbody radiation analysis to confirm the then-existing thermodynamic models. The outcome of his analysis was the creation of quantum physics.

Proposition 3: Fallibility of models. All scientific models are subjects of continuous verification (either explicit or implicit), modification, and improvement, which are carried out in the course of systematic scientific research. Any scientific experiment, from the viewpoint of this presentation, can have one of two possible outcomes: (a) it confirms the model it was expected to confirm, or (b) its results disagree with the model. A scientific model remains adequate if it survives the latest experimental verification. A scientific model fails when either (a) new features of known objects or phenomena become experimentally observable but cannot be described by the model (Definition 3), or (b) new objects or phenomena within a given set are discovered but cannot be accommodated within the model. Proposition 3 is equivalent to the rule of K. Popper (1934): a hypothesis is accepted if (usually, as long as) all attempts to falsify it fail. Updating, expanding and modification of a model do not affect its general validity. For example, the current knowledge of numerous details of the Solar system, including discoveries of several planets and dozens of their satellites, had improved the Copernicus model but had not invalidated it. In most cases, however, a scientific model is a fragile, rapidly discarded construct; it survives until the first valid experiment that undermines it is announced. Most scientific models (usually formulated for a small circle of researchers within a laboratory, a university, or an informal scientific group) have a lifespan from several months to several years.

Definition 4: Scientific paradigms. Every science has general models that describe features of very large sets or all of its objects or phenomena. Rephrasing the definition given by T. Kuhn (1962), these general models are called scientific paradigms. Proposition 3 gives the rules defining fallibility of both the local models and the paradigms. Discarding an old paradigm and replacing it with a new one is an event Kuhn called a scientific revolution.

Paradigms are usually long-lived but some of them become inadequate even after hundreds of years of successful application. Such, for example, was the Ptolemy geocentric model of the Solar system: it was successfully used in astronomy and navigation for 1400 years before it was replaced with an initially less precise but more intellectually appealing and simpler Copernicus model. The definitive proof of the Copernicus model and Keppler corrections of planetary orbits came centuries later. Another example of the paradigm longevity is the nature of geological changes. Although the phenomenon itself, slow rising of the ocean floor and descending of mountainous regions, was known from antiquity, its early explanation as local vertical shifts of the Earth crust remained the principal (and a quite adequate) paradigm in geography and geology until the formulation of the plate tectonics model by A. Wegener in 1915.

Proposition 4: Exclusivity of scientific paradigms. At any given moment, only one paradigm of a given set of phenomena is (nearly) universally accepted; a Kuhn's observation. If a conflicting paradigm has emerged, it is initially violently rejected, and for a good reason: the overwhelming majority of "new" paradigms do not withstand the initial criticism. However, experimental verification of a new paradigm is eventually carried out (Proposition 3), although some of such "live-or-die" tests in modern science may be significantly delayed due to their experimental complexity. In addition, scientists are merely human and exhibit all the human traits including a strong desire to perpetuate the paradigm they are accustomed to, especially if they themselves are its authors. The current heated (although mostly under-the-carpet) discussion of the existence and the causes of global warming is a good example. The exclusivity rule does not necessarily apply to local scientific models. It is common to start a particular avenue of research with several conflicting models that provide (nearly) equally convincing explanations for various phenomena (a mechanism of a complex chemical reaction, genesis of a rare or just discovered living organism, etc.). Over time, experimental efforts narrow the field of the models and the best (adequate) model gradually emerges. The development of the current model for the demise of dinosaurs as a result of an asteroid collision with the Earth is a good example of such progress.

3. EXPOSITION: CLASSIFICATION OF SCIENCES

Conjecture 1: Formulation of independent natural sciences. An independent natural science is a combination of models describing a particular large set of natural objects or phenomena. The set is selected based on two irreducibility criteria:

1. The gnosiological criterion (the main criterion): a "special quality" of a given natural science is defined by the Hegel's maxim about the accumulation of quantitative changes to the level when a new "quality" emerges.

2. Technical irreducibility criteria: either temporary or principal irreducibility of one science to another due to model complexity or time/space limitations of its reduction.

The term "an independent natural science" implies the existence of dependent natural sciences. The latter are defined below in Lemma 1.

The gnosiological criterion is subjective; it is strictly a peculiarity of the working of the human mind. In practical terms, a science is regarded as independent because (and until) its paradigms are regarded adequate for the everyday use within the science. The second (technical) criteria apply when an attempt is undertaken to describe (to reduce) one natural science strictly in the terms of another natural science. If such an attempt is successful, the science is qualified as a dependent natural science (Lemma 1). If such an attempt is not successful, the failure can be explained by two circumstances. The first reason is a temporary technical limitation, an insufficient robustness of the current model and the current technology, for example, the computational power. The second reason for the failure is caused by a principal technical difficulty. This difficulty can be a time limit, an impossibly large amount of time required for a complete quantitative reduction of one science to another, or a space limit, a prohibitively large physical space required for a complete record of all the calculations involved in the reduction of one science to another. There are situations when it is not clear yet whether a particular technical irreducibility criterion is merely temporary or the principal one.

The subjectivity of the main gnosiological irreducibility criterion is emphasized by the fact that the rules of recognition of the "new quality" and, therefore, the number of independent sciences, have changed over time. Several examples:

1. Early astronomy dealt with movements of celestial objects in the field-view of an unaided human eye. This science was completely separate from the early physics (mostly mechanics). Many centuries have passed before a clear understanding of astronomical objects and their apparent movements in terms of physics was developed.

2. One of the paradigms of the 18th-century chemistry was that the chemical transformations of "organic" compounds occurring in living organisms are principally different from the chemical reactions of "inorganic" compounds taking place in laboratories. Only after chemists were able to synthesize typical "organic" chemical compounds from inorganic materials (starting with the synthesis of urea by F. Wohler in 1828), the identical nature of organic and inorganic chemical substances became an acceptable concept.

3. The principal qualitative difference between humans and other living organisms in biological terms was the major paradigm of biology before Darwin. This

concept was gradually diluted starting from the 18th century. The completion of the human genome project and complete genetic analysis of many living organisms were the final demonstration of full reducibility of the human biology to the biology of primates and other mammals.

The above examples show that natural sciences, over several millennia, underwent a kind of "natural selection" in terms of their irreducibility. Historically, a large number of apparently independent natural sciences were developed: geography, medicine, astrology, astronomy, physics, alchemy, botany, chemistry, zoology, geology, paleontology, etc. (Some of the original "sciences"; *e.g.*, mathematics, history and economics, are not natural sciences). Over time, some of these sciences were recognized as nonsense (astrology, alchemy), some withered due to ending of meaningful experiments, such as geography (although this science was rekindled with the discovery of new "geographic" features on the ocean bottom), others merged as branches of more general disciplines (botany, zoology and paleontology became branches of biology), still other remained conceptually intact (chemistry, physics). In parallel, new scientific disciplines have appeared (e. g., genetics) and were accommodated within the already existing sciences. The outcome of this selection, which was mainly concluded in the second half of the 20th century, is the list of currently "irreducible" or "independent" sciences given in Proposition 5.

The author realizes that Conjecture 1 lacks rigor. However, the concept of gnosiological irreducibility of some natural sciences is useful in two respects. First, the number of independent natural sciences is small (see Proposition 5) and particular reasons to qualify any given science as irreducible can be formulated separately for each one. Second, the ultimate goal of this presentation is to undermine some of the generally accepted irreducibility principles (Conjecture 2).

Proposition 5: **Classification and hierarchy of natural sciences**. Four independent natural sciences currently exist; they are (using their historical names): physics, chemistry, biology, and psychology. Each science is regarded as independent based on the gnosiological criterion of irreducibility and on one or both technical irreducibility criteria (Conjecture 1).

The four independent natural sciences form a hierarchy:

Physics

↳ **Chemistry**, describes the structure of molecules and molecular transformations involving external electron orbitals of atoms and molecules.

↳ **Biology**, describes the constitution and behavior of living organisms. The latter are defined as associations of two types of biopolymers, proteins and ribonucleic acids. All living organisms possess two attributes, metabolism and ability to reproduce.

↳ **Psychology**, which is narrowly defined here as the behavior of individual humans related to their self-awareness, intellect, and emotions.

The definition of physics as a natural science cannot be easily given in positive terms but only in the exclusive sense: physics and its dependent sciences develop models for all natural phenomena and objects which are not the subjects of chemistry, biology, psychology, and their dependent sciences.

The above classification and definitions of natural sciences is narrower than the common usage of the respective subjects but have an advantage of uniformity. Two examples help to clarify these definitions:

1. The primary structure (the chemical structure and the chain composition) of proteins and polymeric ribonucleic acids is the subject of chemistry. The secondary structure of proteins and ribonucleic acids (local and global conformation) is the subject of physics. Only spatial rearrangements of ribonucleic acids occurring in the course of reproduction and rearrangements of the tertiary structure of proteins occurring in the course of metabolism and reproduction are the proper subjects of biology.
2. Processes and structures that define the "physical plant" of psychological phenomena (transport of signals in the brain, physical elements in the brain responsible for memory, etc.) are biological, chemical, or physical in nature. Psychology deals only with the outcome of these processes manifested in human "psychological" behavior, as opposed to human biological behavior.

Lemma 1: Dependent natural sciences. A dependent natural science is a subclass of one or several independent natural sciences describing a narrow set of objects or phenomena. Their paradigms and relationship with independent natural sciences are described in Proposition 6.

Historically, the names of natural sciences were derived from the subjects they investigated: stellar astronomy studied stars and, later, their associations (star clusters, galaxies); geography studied large-scale features on the Earth surface; geology studied composition, formation, and distribution of minerals; botany studied plants, etc. Most of these historically defined sciences are dependent sciences of the four independent sciences listed in Proposition 5: astronomy is a branch of physics, geology is a branch of chemistry and physics, botany is a branch of biology, etc. There exists also a subclass of natural sciences that was deliberately designed as dependent: physical chemistry, biophysics, biochemistry, etc.

Lemma 2: Dimensionality of natural sciences. For the purpose of the present exposition, any natural science, both independent and dependent, has two dimensions, the width and the depth. The width of a science is the scope (the number) of objects and phenomena covered by its models. This dimension is self-evident; it can be either finite or infinite. The depth of a natural science (or, if one prefers, its height) is the degree of the approach of its paradigms to "final paradigms" which are not the subject of scientific revolution anymore (see Conjecture 2 below). If the word "depth" is used to describe this dimension of a natural science, then its final paradigms can be called "bottom" paradigms; if the word is "height", the "ceiling" paradigms.

Conjecture 2: Existence of final models and paradigms. A final paradigm of a given independent natural science is reached when the paradigm is expressed (in principle, *i.e.*, at least qualitatively or semi-quantitatively) in the terms of the independent natural science one step above it in the hierarchy of the sciences shown in Proposition 5. As mentioned above (Proposition 2), any model, in the layman's language, is adequate if it currently gives precise and detailed answers to all the questions of "how". The final model also gives precise and detailed answers to all the questions of "why" using the terminology of the science one step higher in the hierarchy of independent natural sciences. Rephrasing C. Peirce (1878) on the subject of the "absolute truth", one can state that the final model of a particular phenomenon is reached when such a model is claimed not to be the subject of any principal change in the future, although refinement of the model is both expected and inevitable.

For modern-day scientists, the final paradigms in natural sciences (they are listed below) look as bland generalities devoid of any novelty or originality. This blandness is an essential feature of the final paradigms; it signifies their universal acceptance and immutability. However, historic analysis of any such final paradigm shows that its "finality" is usually quite recent; some final paradigms are merely 30-50-years old.

The qualifier "in principle" in the definition of a final model reflects the existence of possible technical limitations that can prevent a full quantitative reduction of models of one science to those of another science. For example, the electronic structure of a complex molecule, one of the main subjects of chemistry, can be, in principle, completely predicted by solving the Schrödinger equation for the molecule's structure. However, a complete solution of such an equation for relatively large molecules (for example, molecules containing more than eight-to-ten atoms) may not only by impossible now, due to the limitations of current computers, but may never be possible due to space limitation: the number of units of information to be computed and recorded may exceed the number of atoms in the universe (an observation by W. Kohn).

4. PARADIGMS OF INDEPENDENT NATURAL SCIENCES BASED ON PROPOSITION 5, LEMMA 2, CONJECTURES 1 AND 2.

Chemistry. Chemistry, in the terms of its definition in Proposition 5, has an infinite width (scope): there is no theoretical limit to the number of chemical compounds (molecules) that can potentially exist and can be synthesized.

All current paradigms in chemistry are final. Chemistry has four paradigms and they all are expressed in the terms of physical objects and phenomena:

1. The chemical structure of matter and chemical reactions are determined by properties and transformations of atomic ensembles (molecules). This paradigm, the atomic and the molecular structure of matter, has been transformed over two centuries from a merely speculative model to the definition of chemistry as such.
2. Periodicity of chemical properties of elements is determined by the quantum structure of their external electron orbits. In some cases, the penultimate electron orbits also affect the elements' chemical properties. This paradigm, often presented visually as the Periodic Table of Elements, has become the final paradigm in the mid-20th century when the underlying physical reasons for the earlier empirical model developed by D. Mendeleyev in 1869 were formulated as an extension of the quantum model of the atom.
3. The structure and all chemical properties of molecules can be, in principle, exhaustively described by quantum chemistry (which is a branch of quantum physics).
4. Transformations of molecules in a chemical sense (chemical reactions) involve rearrangements of their external electron shells (molecular orbitals). The description of these transformations is also a subject of quantum chemistry.

Of course, there are large areas in the theory of the structure and reactivity of chemical compounds that do not have exhaustive quantitative interpretations yet. This deficiency, however, is temporary and does not contradict the statement that all chemical paradigms are formulated in the terms of physics and are final. Chemistry as an independent natural science has reached its "bottom". The acknowledgment of the finality of chemical paradigms is represented, for example, by the statement of P. Dirac about the end of chemistry: chemistry has become merely the physics of external electron orbits in atoms and can be in principle, and, for a few light atoms and the simplest molecules in practice, calculated *a priori* using the Schrödinger equation. This statement, in spite of its intended high-handedness, provides the reason why chemistry remains an independent natural science from the human viewpoint. Potentially, a physicist can use the Schrödinger equation and calculate properties of all electronic orbits in an atom, both internal and external. The theory of internal electron orbits, the subject of physics, is a relatively straightforward and dry science; it is important only for some spectroscopic applications. On the other hand, the theory of external electron shells in molecules is overwhelmingly more complex because it describes a large set of different possible molecular orbitals in a (potentially) infinite variety of molecules. This complexity is what can be called, in human terms, the "new quality" of chemistry compared to physics. In practice, this complexity resulted in a gradual abandonment of attempts at exhaustive calculations of molecular structures using the Schrödinger equation and the development of deliberately approximate (but much faster and sufficiently precise) computational techniques, such as the density functional method. This complexity is especially apparent when one considers the last chemical paradigm listed above, the one about chemical reactions as a subject of quantum chemistry. Although the essence of this statement is not under question, practical obstacles to its implementation are truly insurmountable. Only recently the most primitive example of a chemical reaction (a reaction completely useless for a chemist), the one between a hydrogen atom and a deuterium molecule, was finally resolved in a reasonably strict manner whereas even slightly more complex reactions are beyond reach.

Chemistry provides an excellent example of the verification severity of scientific models and the meaning of the expression "paradigm finality": the establishment of the paradigm of the atom and the molecule. J. Dalton formulated the first scientific concept of an atom in 1808: any atom, in the chemical sense, is the smallest material object that retains distinct chemical characteristics. Virtually every chemical experiment in the last 200 years implicitly tested this hypothesis, simply by calculating expected yields of chemical products based on their molecular structure and the known (relative) weights of the involved atoms. The concept of "the atom" never failed in millions of such experiments. Nevertheless, some serious scientists, such as E. Mach and F. Ostwald, challenged the atomic model as unverifiable in direct experiments. The 20th century saw the rise of a series of spectroscopic techniques which fully relied on the physical existence of atoms: electronic spectroscopy, vibrational spectroscopy, electron spin resonance, nuclear magnetic resonance, mass spectroscopy, etc. Finally, a new experimental technique, the atomic-force microscopy, has progressed in the past three decades to a stage when individual atoms and individual molecules could be routinely observed. From the point of view of the atomic/molecular paradigm, this experimental advance has proved to be a disappointing anticlimax. Direct observations of numerous molecules with the new technique fully confirmed every structural feature of the same molecules deduced many decades (sometimes, centuries) earlier from the studies of chemical reactions and from spectroscopic analysis.

Biology. The formal definition of the science of biology is given in Proposition 5: biology describes the behavior of "living organisms" defined as associations of two particular classes of biopolymers, proteins and ribonucleic acids. These associations are characterized by two attributes, ability to reproduce and metabolism (the last attribute was formulated by F. Engels in 1878). One important point should be made: while chemistry, as an independent natural science, is universal (chemistry on any planet or in any gas cloud in the Universe is the same), the term "biology" at the present time really means "terrestrial biology".

Historically, biology was defined as a natural science investigating all living organisms populating the Earth. Under this definition, biology has a very large but finite width, all species of living organisms on Earth. Within this constraint, biology has six paradigms:

1. All biological objects are associations (usually individual cells or cellular bodies, but may also be aggregates of merely two polymer molecules) containing, as the essential part, molecules of proteins and polymeric ribonucleic acids. This paradigm was fully confirmed in the first half of the 20th century, it is chemical in essence and it is final. Of course, "living" biological associations usually contain a large variety of other chemical compounds, including small inorganic and organic molecules (water, oxygen, organic and inorganic acids and salts, etc.), high molecular weight organic compounds (steroids, alkaloids, vitamins. etc.), and organic polymers (polycarbohydrates, lignin, polyterpenoids, etc.). The above definition leaves outside of biology and assigns to chemistry two particular types of "lifelike" objects: (a) some simple viruses, single-molecular polymeric ribonucleic acids that do not have protein sheaths and do not metabolize but can reproduce, and (b) prions, proteins that exist in an exceptionally stable spatial form, do not metabolize but can "reproduce" via a peculiar physical mechanism.

2. Reproduction in biology is self-replication of ribonucleic acids. This paradigm was formulated in the second half of the 20th century; it is fully chemical in all its details and it is final. Reproduction is usually accompanied by synthesis of proteins or polycarbohydrates and by cell division. There are many details of the reproduction processes omitted in the above definition; all of them are also finalized in chemical terms.

3. The paradigm of biological metabolism is also entirely chemical and it is final. Specifics of metabolic processes depend on the type of a living organism. In the animal kingdom, metabolism proceeds nearly entirely via the enzymatic mechanism, complex sequences of catalytic chemical reactions. It includes disassembling all high molecular weight organic materials consumed by an organism onto low molecular weight "building blocks" (amino acids, small organic acids and esters, organic bases, etc.) and reassembling from them new high molecular weight compounds specific for a particular organism (see the next paradigm). Metabolism in plants additionally uses

"building blocks" absorbed directly from the environment (carbon dioxide from the air, water and nitrogen compounds mostly from the soil) and relies on catalytic photosynthesis for converting these compounds into cell components. As always, there are numerous exceptions, all formulated in chemical terms: some bacteria chemically convert molecular nitrogen from the air, arboreal plants consume water from the air, some parasitic organisms and viruses use "building blocks" provided by the organisms they inhabit, some plants acquire nitrogen compounds by digesting insects and small animals, some plants synthesize proteins, etc. Energy requirements of living organisms (a part of the overall metabolic process) are satisfied via the firmly established chemical routes as well. Although most of the underlying chemical processes of metabolism are already known, expansion and detailing of this paradigm is one of the principal subjects of biochemistry.

4. Assembling new proteins from amino acids proceeds according to a singular mechanism specific to the majority of terrestrial biological objects: a certain sequence of nucleotides within a DNA molecule is copied as an RNA molecule and the latter expresses this information in the structure of the protein it synthesizes. The search for "switching agents", sequences of steps that lead to activation of particular genes or to suppression of their action (known under the general term epigenetics) is currently at the leading edge of the genetic research. It is clear, however, that all these processes are, in essence, chemical reactions. Although their detailed understanding suitable for practical use is many years, maybe centuries, ahead of us, the principle (the paradigm) is final.

5. The paradigm of evolution of living species. This paradigm has two components. First, the evolution proceeds through accumulation of naturally occurring variations in populations; therefore, all the living species populating the Earth now are the "products" of changes in the living species populating the Earth in the previous eons. This part of the evolution paradigm is final; it is purely phenomenological and is the subject of two dependent sciences, paleontology, and paleobotany. The progress of genetics in the 20th century amplified this part of the evolution paradigm by providing the chemical mechanism of the variability *via* mutations, spontaneous chemical changes in the DNA structure.

The second part of the evolution paradigm should, in principle, spell out a particular driving force of the evolution and its mechanism. Until the end of the 20th century, this was the theory of natural selection formulated by C. Darwin in 1859 and later refined by several generations of evolutional biologists. According to them, the evolution proceeds through the naturally occurring process of elimination of the least adopted species in a given population [E. Mayr (2001)]. Two developments lead to modification of this mechanism. First, the discovery of the genetic code in the 30-ties and 40-ties produced a detailed explanation of the chemical mechanism that lead to the variations (mutations in the DNA chains). From this perspective, the natural selection is a filter of acceptable mutations. Second, recent great advancements in our understanding of DNA mutation processes (the existence of "master" and 'slave" genes, the existence of a certain hierarchy in mutation sequences) have led to a radical reformulation of the mutation phenomena and the evolution process in general as a directional rather than a completely stochastic process (Neo-Darwinism). Although the outlines of this new evolution model are still sketchy and have yet to be fully reconciled with the (very successful) Darwin model, it has the potential for a complete reformulation of the evolution model in the terminology of chemistry.

6. The model of the origin of terrestrial life. Only the basic features of this model have been established: spontaneous formation of hydrocarbons and amino acids via the chemical route (for example, in asteroids), self-aggregation of organic molecules and their separation from the aqueous environment in micelles, the initial primacy of RNA (instead of DNA) as the first depository of genetic information and the first biological catalysts (enzymes), etc. All these features are chemical in nature, but the model is not sufficiently developed yet to qualify as a full-fledged paradigm. However, there are no principal reasons to doubt that the full formulation of this model in chemical terms can be eventually achieved.

In conclusion, terrestrial biology, as an independent natural science in the terms of Proposition 5 and Conjecture 2 has not reached the "bottom" yet with respect to its paradigms 5 and 6. However, no obstacles to the eventual accomplishment of this goal can be anticipated at the present time.

Psychology. Psychology is the science investigating the behavior of individual humans related to their self-awareness, intellect, and emotions (Proposition 5). Strictly speaking, human psychology is a subclass of the science of animal psychology. However, psychology of other animals is significantly simpler, in terms of richness and variability of manifestations; and human psychology became, to practical purposes, the main subject of psychology in general. As far as the width of psychology as a natural science is concerned, external manifestations of human psychological behavior, although numerous, are apparently finite.

The development of human psychology was in the past and is still impeded by three circumstances:

1. Experimental difficulties. A human brain is a very compact biological organ densely packed with an enormously large number of microscopic elements, interconnected brain cells of various types. Experiments on the human brain are very

difficult; the techniques used for the purpose are still relatively crude and often obviously inadequate.

2. There are natural moral prohibitions against intrusive direct "experimenting" on the human brain (in contrast to observation by MRI, etc.) except in some cases of medical emergencies or extreme illnesses when a physical intervention is called for.

3. Some aspects of psychology, first of all, those related to intellect, are often claimed to belong to social disciplines and, therefore, are declared unsuitable for the type of an unrestrained experimental investigation required in natural sciences (Propositions 1 and 2 and Definitions 1 and 3).

Human psychology developed several paradigms:

1. Physiologically, the Homo Sapience species belongs to the class of big apes. All its chemical aspects and most of its biological features are identical to those of the apes; many are similar to those of other mammals (C. Darwin, 1871).

2. All types of activity studied by psychology reside in the human brain (F. Crick, 1994) and, at least in principle, are experimentally accessible. Rephrasing S. Pinker (1997), "the mind is what the brain does".

3. Most basic human emotions (hunger, fear, pleasure, sexual desire, etc.), as well as ability to dream, are similar to those in mammals. They are biological and chemical in nature.

4. A complex psychological behavior in humans is a product of their evolution and can be, at least in principle, deciphered through the analysis of the behavior favoring survival of the Homo Sapience species during the earliest (and the longest) period of its development [S. Pinker (1997)].

5. The human brain has an inborn ability to develop models of the natural world (see Proposition 2). This paradigm is genetic (*i.e.*, biological) in essence. The degree of complexity and sophistication of the models are adequate for successful functioning of early human individuals in the surrounding (macro-scale) world and in the human society. One of the most important of these inborn abilities is the ability of an early, rapid and extensive acquisition of language, both grammar and vocabulary, see N. Chomsky (1957) and S. Pinker (1994). This makes linguistics (at least, its theory) a branch of psychology. However, the model-building ability of the brain developed by the early humans is stretched to the limit or totally inadequate in describing micro-scale phenomena using quantum mechanics [P. Teller (1997)].

The first three paradigms of psychology are biological and chemical in nature and are final. At the present time, there are no obvious obstacles to refining the rest of the paradigms in psychology and thus achieving the condition of Conjecture 2, however far removed to the future this moment may be.

Physics. Physics is a very heterogeneous science. Because the formulation of physics as a natural science (Proposition 5) suffers from the absence of a positive definition, the issue of the width of this science is uncertain. It is clear that the two sets, those of physical objects and physical phenomena, are large and diverse; however, it is impossible to state whether they are finite or not.

According to Conjecture 2, physics as a natural science has no "bottom" because, formally, it does not have a predecessor in the hierarchy of natural sciences (Proposition 5). Some paradigms in physics will never become final. It is thus instructive to review, very briefly, some of the current paradigms of physics in the light of this statement:

1. Most macroscopic objects and phenomena are described by two paradigms: the atomic nature of matter and the wave nature of radiation. Both these paradigms, although adequate for most practical purposes, are the products of the 19th century and are obviously not final.

2. Mechanics is described by the model called the special theory of relativity (A. Einstein, 1905). In the particular case of objects moving at relatively low speeds, the Newtonian mechanics is a fully adequate practical model for most macroscopic objects.

3. The structure of matter is described by the model called quantum mechanics (M. Planck, A. Einstein, N. Bohr, E. Schrödinger, W. Heisenberg, 1900-1927).

4. The model called the general relativity theory describes the phenomenon commonly called "gravity" (A. Einstein, 1915).

5. The behavior of very large associations of independently moving small bodies subject to external forces is described by a group of very precise models called "laws of thermodynamics". In the 19th and 20th centuries, these models (which were originally empirical) were theoretically fortified and were modified to account for the quantum state of each constituting body in the association.

6. The structure of subatomic particles is described by a series of ever-developing models. The applicability of a particular model is determined by the particle's energy. All these models are based on quantum mechanics principles. The development of the models started in 1911 (after the discovery of a positively charged atomic nucleus by E. Rutherford) and continues to the present day.

7. The "standard" cosmological model currently describes the events immediately following the creation of the observable Universe. The "Big Bang" phenomenon by itself is not a subject of any coherent physical model yet but the first attempt, a membrane collision in the string/membrane model, is gradually taking shape.

Two good examples demonstrating futility of formulating a "final" paradigm in physics are the models of mass and gravity. Newton gave profoundly significant quantitative answers to two "how" questions: gravity is: (a) universal, and (b) in the case of two isolated bodies, it is expressed according to a particular simple equation. However, Newton, who understood complexity of the problem of action at a distance well, refrained from saying "why" and adamantly refused to "feign hypotheses" about the nature of the gravitational attraction. Einstein produced the next fundamental answer to the question of "how" by demonstrating that gravity and inertia are two manifestations of the same phenomenon and that gravity can be expressed as a change in the geometry of the space-time continuum. Recently, quantum mechanics found another way to reformulate the issue of mass by describing the inertial mass as a resistance of the Higgs boson field to the movement of a body imbedded in it. Now that this model is finally proved experimentally, it will replace one current paradigm, that of general relativity, with another one, quantum mechanics. Still another candidate for the explanation of the gravity phenomenon, in particular, its weakness compared to other elemental forces, is the superstring/membrane theory.

There were several attempts, starting with Einstein, to produce a unified physical paradigm. These attempts have not yet yielded a universally accepted and universally applicable model although some variants of the superstring and the membrane models may come close, for example, in describing black holes. On the other hand, physics is witnessing a rapid approach of the next scientific revolution. First, recent experimental progress in splitting/polarization of individual photons (processes governed by the quantum mechanical paradigm) discovered the "entanglement" phenomenon and started contradicting the principal concept of the special relativity model concerning the maximum permissible propagation speed of any signal. Second, the current cosmological paradigm is becoming even more complicated after the recently confirmed validity of the cosmological constant in the gravitational model of the Universe (dark energy) and a predominantly unidirectional movement of all galaxies in the Universe (dark flow). If the existence of these phenomena withstands a future experimental verification, they will add other paradigms to physics, the existence of a new weak force, antigravity, which is the property of space itself, but without any clear understanding of "why".

It is reasonable to state that Conjecture 2 will hold in the future and that physics as a natural science will remain "bottomless".

Dependent natural sciences Dependent natural sciences are subclasses of independent natural sciences (Lemma 1). According to Lemma 2, they are also two-dimensional; each has the width (scope) and the depth. One can slightly reformulate Conjecture 2 and to state that all dependent natural sciences have clearly reachable bottoms, *i.e.*, their final paradigms are already (or are expected to be in the near future) reformulated by expressing them exclusively in the terms of their parent independent sciences. Several examples clarify this statement:

1. Stellar astronomy is one of the oldest natural sciences. Nuclear decay and synthesis reactions were experimentally discovered in the first half of the 20th century. Physics of high-temperature gas plasma is being developed starting with 1960s. The structure and evolution of stars are adequately described by the models of nuclear synthesis (H. Bethe, 1938) and by plasma physics. This makes stellar astronomy a dependent science of physics. The nature and the properties of black holes is also a vigorously developing subject of physics.

2. Infectious diseases in humans and mammals are one of the oldest subjects of medicine. Bacterial biology (L. Pasteur, ca. 1850) and viral biology (the first half of 20th century) are the branches of terrestrial biology that adequately describe virtually all infectious diseases. This makes medicine, as far as infectious diseases are concerned, a dependent science of biology. Other subjects of medicine are also expressed in terms of biology (for example, diseases of the immune system), psychology, and polymer mechanics, a branch of physics (muscle tear, broken bones, etc.).

3. Geology, as a science describing the structure and formation of minerals (both terrestrial and those on other planets), has all its models formulated in the terms of inorganic and organic chemistry and crystallography (a branch of physics). The current geological paradigm for the dynamics of the Earth surface, the plate tectonics model, is also formulated in the terms of two physical models, mechanics of large elastic bodies and rheology of viscous fluids.

4. A large family of engineering sciences (mechanics, strength of materials, electrical engineering, chemical technology and engineering) was deliberately developed as dependent sciences of physics and chemistry.

Distinctions between dependent natural sciences and branches of independent natural sciences are often merely linguistic ones. The scope of a dependent natural science is usually defined historically, on the basis of a set of objects the science describes. On the other hand, all independent sciences have branched out over time and formed special disciplines with their own sets of subjects and special models: physics of low-temperature phenomena, polymer chemistry, genetics, etc. It should be stressed that the "near-finality" of paradigms of dependent natural sciences does not signify the finality of their models. Particular models in dependent natural sciences can be subjects of improvement, modification, or a complete replacement; the same processes as in independent natural sciences. A good example is the model of global warming in the climate science, a dependent science of physics and, partially, chemistry. Currently we are witnessing the competition of two models explaining global warming, (a) an increase in the concentration of carbon dioxide in the atmosphere, and (b) a decrease in the frequency of low-tier cloud formation due to the decrease in the cosmic ray flux through the atmosphere which, in turn, is dependent on the solar activity. Whatever the outcome of the competition may be, both models are based on well-understood physical models describing the behavior of water-saturated gases and infrared spectroscopic parameters of various components in the Earth atmosphere.

5. CONCLUSIONS

Philosophical hypotheses about the essence of natural phenomena (philosophy of nature) were initially based exclusively on logics and did not require (indeed, were suspicious of) experimental testing. The emerging scientific model of the human intellect (based on the current evolution paradigm) states that the human brain is a biological organ that has been developed as a survival tool of the Homo Sapience species. It is well suited for the construction of scientific models for macroscopic events and macroscopic objects in situations when straightforward "thought" experiments are possible. However, the human brain utterly fails in modeling microscopic phenomena and directly unobservable objects in the absence of targeted experimental data. Current models of most phenomena and objects in independent natural sciences are based on examination of microscopic objects (atoms, molecules, biological cells, etc.); they are not intuitive (not "logical"). *A'priori* logical modeling of complex microscopic phenomena is nearly always doomed to failure after relevant experimental data are produced. As a result, philosophy of nature has ceased to exist as an active subject of philosophy at the end of the 19th century and was gradually replaced with positivism according to which any science, at any given moment, ends with the formulation of adequate models.

When discussing the subject of classification of natural sciences, one more issue should be considered, the dialectics in our attitude toward a principle possibility of science classification. It is quite common to assume that scientific disciplines are characterized by disunity and by fluid patchwork relationships, *i.e.*, to propose that relationships between different natural sciences should not be discussed without the historic context [N. Cartwright (1989, 1999), J. Dupré, 1993, 2003)]. This author emphatically disagrees with this position. Sooner or later, any subject in a science (except in physics, as described above) and in philosophy of science matures sufficiently so that its general outline becomes discernible. To allow a poetic license: the "Sagrada Família" cathedral in Barcelona is under construction for over 120 years. For the first 50 years this indeed was a disunited, patchwork place. However, although the cathedral will not be completely finished for at least another 40-50 years, its general outline and many details are perfectly clear by now. We do not definitely know yet how some of the interior spaces in the cathedral are going to look like, but we are certain that the four corner towers will stand where they stand now and that their interconnections with the central tower will not be reconstructed. Such a moment of emerged transparency has been reached in philosophy with respect to classification of natural sciences.

The first part of the article lists some ideas about the structure of natural sciences (which are viewed as intellectual constructs) strictly in the positivistic terms. However, the above-proposed classification provides an opportunity of selection between positivism and pragmaticism. It also appears possible to provide some kind of quantification for the pragmaticistic approach. One can view pragmaticism as a "bridge philosophy" of science between absolute positivism and the concept of a given natural science as a collection of final paradigms formulated in terms of models of an above-positioned science in the science hierarchy. Independent natural sciences are positioned at different points on the "bridge". Physics, with respect to its core paradigms, is now and, apparently, for the foreseeable future will remain a purely positivistic science. Chemistry has reached the state of the final paradigms, which means that the "final truth" in chemistry, in qualitative terms, is already known. Biology and psychology are in transition between the positivistic set of adequate models and the state of final paradigms. The main concept of pragmaticism is fully applicable to them: the "final truth" in these two sciences is what we have learned in the past, what we are learning now, and what we will learn in the future.

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