The Role of Philosophy as a Guide in Complex Scientific and Technological Processes

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Abstract

Probably the most challenging issue in science and advanced technology is the ever increasing complexity. The term complexity refers to the experience that the complex whole is more than the sum of the parts. Emergence of new properties is observed at all levels, from relatively simple physical systems up to high-end evolution in biology or state-of-the-art microprocessors in technology. In this study an effort is made to arrive at an understanding of the underlying ontological basis in terms of the classical philosophy of Aristotle and Aquinas. In addition, the value of philosophy is emphasized as a means to develop the capacity for intuition. Only with this capacity it is possible to acquire an understanding of the great variety of concepts needed in the multidisciplinary approach to complex systems.

Keywords: complexity; emergence, hylomorphism, analogy of being, intuition

Outline

1. Introduction

Many of us have played with mechanical toys as children, mostly nicely arranged in a box. The challenge then was to build your own small car, elevator or other things just by screwing and putting together all the small parts. Getting older you could use more parts and tackle advanced problems like a car with a small motor and gears. This step was not just adding more parts. The interaction between movable parts went beyond a simple relation where only two or three degrees of freedom were involved. It was becoming a complex problem that exceeded the intellectual capacity of an eight-year-old child.

Science and technology in a certain sense is repeating this experience. We are now increasingly confronted with scientific problems that, solvable in principle, need nevertheless new approaches. We understand, e.g., quite well the properties of a transistor. The interaction, however, of more than a billion of them in a state-of-the-art microprocessor is only known approximately. Figure 1 illustrates the traditional 'ideal' approach to high level science. In a static approach a broad basis is laid of fundamental knowledge. Layer by layer, higher levels of increasingly applied knowledge and diminishing extension can be obtained ending up with the desired high-tech extremely specialized application. The interaction between the layers is in this standard approach restricted only to the nearest lower or higher layer. This approach seems to be very attractive, it fulfils the Cartesian demand of *clare et distincte* (clear and distinct). The progress in knowledge is based on understanding the supporting layer. It is completely controllable and based on a solid basis of knowledge where the next step is only taken after a thorough understanding of the previous layer. The problem now is that it does not work in practice -the number and lifetime of scientists are limited- nor in theory, as the whole is more than the parts as will be shown below.

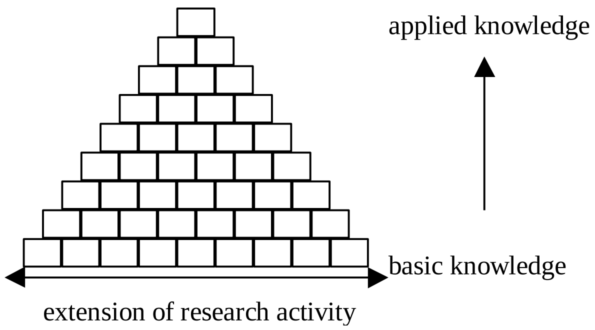

Figure 1: Conventional, static approach in order to arrive at the specialized knowledge needed in high-tech applied science.

Coming back to the example of modern microprocessors, we observe that we do not know in detail all the properties of the building block, a single transistor. The behavior of millions of them, nevertheless, is sufficiently understood to start a technological development comparable in impact to the 19th century industrial revolution: the information technology.

A recent symposium organized by the Pontifical Academy of Science dealt with *Complexity and Analogy in Science* (Arber et al. 2015). Several ideas forwarded in this symposium support the approach in the present study. A few contributions will be explicitly quoted, when it leads to a better understanding or when acknowledgment would be justified. As an example one could mention Pierre Léna who described in the following words the challenge for the traditional approach in science (Léna 2014):

> The traditional model of science education - disciplinary, analytical and deductive - is challenged by the complexity of the world to be deciphered and the complexity of the science to be communicated.

In the following section we try to obtain on the basis of a few examples some characteristics of complexity in science and technology. In a previous study, issues regarding complexity in biological systems have been analyzed with a comparable philosophical approach (Driessen 2015).

2. Complexity in Science and Technology

The first striking sensation one experiences in a high tech environment is its multidisciplinary setting (Driessen 1995). As an example one could remind the above mentioned microprocessor chip. It is based on physical phenomena that only can be understood in terms of solid state physics based on quantum mechanics. The design of such a device is the field of electrical engineering, information science and applied mathematics. The production is based on advanced optical lithography in conjunction with mostly chemical deposition and etching technology. Advances in the field are the result of detailed studies involving the systematization of a large number of empirical results. As a consequence, no single scientist is able to have a complete knowledge representing the state-of-the-art of the relevant fields. Each discipline has to contribute to a complex whole that a single human mind is not able to understand on its own. The specialization and the extension of the knowledge base is so far developed that even within a single discipline hundreds and even thousands of scientists are working simultaneously to arrive at the desired technological product or system. In addition new generations of the product are following each other with increasing speed. If a microprocessor producer, for example, is not able to deliver an improved type within a few months, he will lose within short time his leading position. This means that research and development, intuitively considered open ended, is done in a project environment with tight deadlines and milestones.

The above given example can be extended to even more dizzying proportions by considering that meanwhile thousands of millions of microprocessors are connected on a global scale. They interact in the probably most complex man-made technological system, the World-Wide-Web. This, in fact, can be considered as one single distributed computer system. The number of disciplines and not to say the number of scientist contributing to its development is exceeding any extrapolation made only some decades ago.

Considering now complex systems in general, one can distinguish several characteristic properties (Burgers 2011):

- One does not encounter a single preferential level of detail that allows the adequate description of the system. Instead one has to work with several levels of description.
- On the micro level the system consists of a very large number of separate elements that interact with each other.
- There is emergent behavior, a spontaneously arising activity at the higher level. This activity at the macro level with new structures and interaction is not the

> result of external control and is not directly reducible to the properties of the micro-elements.

Going from the object of research to the subject, the engineer or scientist, one also encounters the challenge of complexity. In fact, the human person can be considered as a complex system. Melanie Mitchell writes in the introduction of a textbook *Complexity, a Guided Tour* (Mitchell 2009):

> One of my motivations was in fact, how people think – how abstract reasoning, emotions, creativity, and even consciousness emerge from trillions of tiny brain cells and their electrical and chemical communications. […] It was becoming clear that the reductionist approach to cognition was misguided – we just couldn't understand [how thinking arises from brain activity] at the level of individual neurons, synapses, and the like. Therefore, although I didn't yet know how to call it, the program of complex systems resonated strongly with me.

One could ask how to prepare the future scientist or engineer for the challenging tasks in the increasingly complex technical environment. P. Léna states that one should already start at the age of children and gives a few suggestions for their basic education (Léna 2014). A special type of person is needed in order to overcome the pyramid paradigm of Fig. 1. About 25 years ago an inquiry has been made among Dutch companies that employ scientists for their Research and Development departments. The following two quotations from different reports indicate a trend in accordance with the changing world of science as described above. An advisory commission stated in 1992 (AWT 1992):

> *Companies have the experience that recently graduated scientists are not able to combine and integrate the knowledge of the different disciplines.*

Another commission concluded specifically about the role of physicists in 1994 (de Vries 1994):

> *Physicists must put more effort in learning to work in a multidisciplinary environment and within multi-disciplinary projects.*

Meanwhile Universities and other educational institutes have followed these recommendations and changed drastically the teaching methods. They reduced classical lectures and introduced alternative forms like working in multidisciplinary project-groups, performing case studies and stimulating students to work as trainee in a real-life professional environment. In this transition, multimedia technology and instantaneous access to ever increasing knowledge databases have surely played an important facilitating role.

In order to arrive at an analysis of this new situation originated by the increasing complexity of science and technology one has to move to a meta-level that transcends the realm of science, see e.g., (Arecchi 1997). Psychology and sociology could contribute to this analysis but being a discipline among many others, they are not able to provide the desired 'helicopter-view'. Philosophy is a better candidate as it can assess the role of the different disciplines and, especially, provides an ontological basis of complex systems. The observation of Strumia supports this view (Strumia 2007):

> *Complexity, whole* and *parts, dynamics, attractors, chaos, order, information, self-organization, teleonomy, finality, project, intelligence, mind, concept, self-similarity, analogy,* etc., are the new words arising today, practically, inside *any science*. They sound similar, even if not identical, to some (Latin) terms of ancient (Greek and Mediaeval) philosophy of nature, metaphysics and logic: *complexio, totum et partes, motus, quies, ordo, forma, finis, intellectus, anima, intentio, similitudo, analogia (entis),* etc.

It is obvious that one has to select an adequate philosophical approach. Ancient Geek atomism, for example, would not be sufficient as it focusses mainly on the constituent parts, the atoms. Like in the reductionist approach the ontological basis of the emerging properties at the higher level is then only weakly given. To find a suitable coherent philosophy, or more specific a coherent metaphysics, is a great challenge. But it is crucial to arrive at a view on reality that makes complexity intelligible. The complex artificial or natural being is not just more of the same. Its phenomenological richness cannot be reduced to the multiplied simplicity of the building blocks.

Our tentative philosophy of complex science (section 5) is based on an analysis of the cognitive processes in human beings (section 3). It is shown that the elaboration of concepts and the way one arrives at the understanding of the phenomena exceed the possibilities of a formalized, mathematical approach. In section 4 the ontological basis of complexity is given based on concepts of the classical philosophy of Aristotle and Aquinas: hylomorphism and the analogy of being. This approach takes into account the phenomenological richness of an object that with respect to its material principles is composed of simple building blocks. Based on the analogy of being and the distinction between material and formal principles a hierarchy is proposed in the material world. A similar hierarchy has been established by the Nobel Prize Winner P.W. Anderson (Anderson 1972). He illustrates with examples taken from physics that the whole is more than the sum of the constituent parts. Section 5 then, combines the results of the foregoing two sections and gives a brief discussion of some important aspects of our tentative philosophy of complexity. Finally we present in section 6 our conclusions.

3. Cognitive processes in human beings

In the case of human beings and animals the acquisition of knowledge about the outer world starts with the information supplied by the senses. The next steps in the information processing can be quite similar for both, men and animals. But only in the case of human beings it will eventually end up in notions or concepts. If a human being arrives at this stage he says, "I see", or "I understand". The concept is based on senses and reasoning, but there is more. A personal experience may serve as an illustration. Being 12 year old we learned on High School the basic concepts in physics. I could remember the difficulty I had to grasp the formal concept of acceleration. I had the experience of being moved in a car, or of a stone falling down due to gravity. But I could not understand our teacher when he made an analogy to velocity. This quantity can be defined as the change in position per unit of time and accordingly acceleration can be considered as the change of speed in unit of time. The formal concept of acceleration that allows the mathematical formulation of Newton's law was too much for me at that time. Only after some time and rethinking the arguments I was able to understand. I could grasp the meaning; I had, what the Germans call an 'Aha Erlebnis' (Eureka, *I-see* experience), a term coined by Karl Bühler. It is interesting to note that before that understanding I could apply the formulas and calculate the numerical value for the acceleration.

This is a very general situation well known to students of physics. One is able to follow all mathematical steps and to derive the correct results, but a real understanding of what one is doing is largely missing. In the case of the formalism of quantum mechanics this quite unsatisfactory situation extends even to Nobel Prize Winners. Richard Feynman, a real genius, for example, states (Feynman 1965):

> I think I can safely say that nobody today understands quantum mechanics.

Scientific work is more than the correct application of a certain formalism. In each branch of science a broad variety of concepts have been developed that are shared by the scientific community. These concepts are the basis of what is called the scientific language of this specific discipline. Concepts constitute the logical basis of judgments or statements. They are the building blocks, as a judgment consists in a logical relation between two or more concepts. Judgments evidently can be true or false, or in between, if the concepts or the relation expressed in the judgment give way to a certain ambiguity.

In a certain sense one can attribute also to concepts the qualification of true of false. This is meaningful if one considers the agreement with the accepted language in this specific discipline, or if one considers the adequacy to arrive at a consistent formal approach. The great scientist is the person who is able to understand the full richness of concepts and who is able to transmit this richness to non-peers in such a superb way that those arrive at the "Aha-Erlebnis". The wrong choice or the less adequate formulation of concepts can inhibit largely the progress in science for individuals and even for the whole scientific community, as the history of science demonstrates. As an example of a mental barrier one may remind the consequences of the mechanistic world picture with roots in Laplace and especially in 19th century classical physics. In this view the starting point is the axiom that all physical phenomena can be explained by means of spatial movement of well-defined bodies and particles. Consequently, the two new physical theories of the 20th century, relativity and quantum mechanics, are missing completely intelligibility.

Closely related to the concepts is the intellectual capacity of man that is called intuition. The common expression after having received a satisfactory explication "I see" indicates that the process of understanding is not only the sequence of rational steps, in traditional logic called syllogism. At a certain moment the explanation is sufficient, one sees (in Latin *intuere*) the solution of the intellectual problem. It is remarkable that the classical Greek word for "to see", theorein (θεορειν) seems to stress the importance of the intuitive contribution in a theoretical approach. Often the reverse is happening. The scientist intuitively sees the solution of a problem; the work now is to prove formally the correctness of the intuitive approach. This double structure in the cognitive process reveals the double structure in the rational activity of human beings: on the one hand the formal, analytical approach based on reasoning and on the other the intuitive, synthetic and creative approach where one sees directly and immediately the solution of an intellectual problem. Both are necessary and have to be developed in scientific education. The formal, mathematical approach is largely used in science and leads to results expressed in the Cartesian ideal of being *clare et distincte*. Support of a computer can simplify largely this kind of intellectual effort. The intuitive way seems to be especially necessary for artists and others involved in creative activities. Nevertheless one should bear in mind that even in the exact sciences creativity is necessary to arrive at major breakthroughs. Max van Laue explains (von Laue 1950):

> The tenet that the scientific experience of truth in any sense is "theoria," i.e., a view of God, might be said sincerely about the best of them.

Intuition, being able to synthesize and creativity therefore have to be developed besides the ability to carry out a formal, analytical approach. Once again one could refer to (Lena 2014).

4. Hierarchy in the material world and the analogy of being

In this section we will examine in detail the ontological basis of complexity. The main question that will be discussed is whether the whole is more than the constituent parts. In other words, is there real something new in the complex being, or is complexity something more related to our way of thinking. Does it mean that we call it complex because the whole exceeds our restricted intellectual power or the capacity of our computers? In order to arrive at an answer we carry out an analysis based on the metaphysics of Aristotle and Aquinas and make use of the analogy of being. In addition we use the distinction of material and formal principles (hylomorphism) to clarify the ontological structure of material beings.

When analyzing the word "to be" one discovers a very peculiar structure. One can speak about the being of a man, an idea, a dog, an atom, a droplet of water, a specific color, or even of the being of First Cause. The being of all of these realities is surely not the same, as the being of a droplet or an atom is much weaker and less pronounced than the being of a dog or a man. The being of an idea is even more peculiar, as it has to be in someone or something else, in the head of someone or written down - materialized - in a piece of paper or another information carrier. An idea participates in the being of something or someone else. One therefore can say that 'to be' indicates different relations, but all seem to belong to a certain class. As Aristotle says in the Metaphysics: *Being can be said in many ways* (Aristotle Metaphysics). In other words being is not univocal, it does not express unambiguously always the same relation, but also not equivocal like the word 'mint', a name of a plant or the name of a place where coins are produced. These kind of peculiar words in the Aristotelian-Thomistic tradition are denominated as being analogical, because they exhibit certain proportionality. The being of man relates to a man as the being of an atom to an atom. They are predicated as more or less and allow certain levels within a hierarchy. This hierarchy is formed by observing that the lower beings participate in the being (esse) of the higher beings. For a recent study of the analogy of being including the impact on theological discussions, see (White 2011).

One, true, good and beautiful are the transcendental properties that belong to any being. In common experience this is implicitly assumed. If we count things, we count units that have certain wholeness. If we consider something as being true, good or beautiful we implicitly assume that it is something with its own being. Consider an everyday situation with a dog approaching us and our comment would be: "Look at these billions of molecules approaching us." Or even worse when contemplating the beautiful face of a young woman one is in love with: "What a beautiful arrangement of biological cells". Our common sense refuses to accept this mental reduction of the whole to its material parts. Intuitively we are able to grasp that one is dealing with a whole.

Closely related to these transcendentals, other words have a similar analogical character. The substance is one of these. With this expression one denominates things (or persons in the case of intelligent beings) that have their own being (*esse*), unlike an idea that exist in an intelligent being. In the case of a human being one easily accepts that one is dealing with a substance. In the case of an atom or an electron it will depend on the context or environment one is considering. If one considers them as a unity with their own being one can speak about a substance, otherwise it is part of a substance (in the case of an atom in a human being) or an agglomeration of substances (if one considers elementary particles). It is worthwhile to quote in some extension A.G.M. van Melsen (Van Melsen 1982):

> We do not hesitate to use this concept (*substantia*) with respect to human beings and animals, but we encounter increasing difficulties when we are applying it to plants, minerals, liquids, gases, beams of light, etc. In the latter cases the concept *substantia* seems to be devoid of any meaning. It does not amaze us, therefore, that science dropped this concept from its vocabulary. Yet with respect to human beings and animals the concept *substantia* cannot be missed whereas, difficult as it may be to indicate other concrete substances, there can be no doubt that material entities do exist. This implies that the analogy of the concept *substantia* should be fully taken into account.

being (ens)	***material principles***	***formal principles***	***discipline(s) involved***
nation	'matter' involved: human beings	laws of nature, moral laws, leading to concepts of politics, e.g. democracy	politology, humanities, sociology
man	matter involved (a.o. celles, organs) similar to other mammals)	laws of nature, moral laws, leading to concepts related to human beings, a.o. ethics	medicine, biology, humanities
animal	matter involved (a.o. cells)	laws of nature, leading to concepts related to animals, e.g. growth, reproduction	biology, physiology
biological cell	matter involved, a.o molecules	laws of nature, leading to concepts related to cells, e.g. cell division	biology, chemistry
artifact (e.g. airplane)	matter involved (a.o. atoms, molecules)	laws of nature, leading to concepts related to airplanes, a.o. travel comfort	physics, engineering, ergonomics
molecule	matter involved (a.o. atoms)	laws of nature, leading to concepts related to molecules, a.o. heat of formation	physics, chemistry
atom	matter involved (a.o. protons)	laws of nature, leading to concepts related to atoms, a.o. radioactivity	physics
proton	matter involved (a.o. quarks)	laws of nature, leading to concepts related to protons	Physics

Table I: Hierarchy of beings with increasing complexity

On the basis of the analogy of being one can establish a hierarchy in beings with increasing complexity, see Table I. Simultaneously with this hierarchy an ordering in the different scientific disciplines is obtained. This table is inspired in part by (Anderson 1972) who discusses in detail the layers related to physics without direct reference to metaphysical issues. A similar approach can also be found by the philosopher Herman Dooyeweerd. He considers a structure of modal aspects of reality with new law-spheres (Dooyeweerd 1936). The hierarchy in the table is established not in a unique way, as different point of views are possible. The first column in Table I indicates the beings or substances in consideration. Referring to Aristotelian hylomorphism, in the next two columns the material and formal principles (causes) are given that determine these beings. Each higher level is based on the foregoing levels (not necessarily all of them) and adds something new mainly due to the increased richness in the formal principles. The new total being is more than the sum of the parts. This is indicated explicitly by adding in the column of the formal principles some of the new concepts that come up at each level.

As intuition is needed to understand the full richness of these terms a purely formalized, quantitative approach using the concepts of the lower levels is not sufficient to arrive at an understanding of the concepts in the higher level. It happened often that the ordering and deeper understanding of concepts in a higher level has led to new disciplines. Sometimes, however, the new discipline does not make use of the disciplines of the lower levels. To give an example, the knowledge of nuclear physics does not help in the development of a scientifically sound human ethic. It will, however, be strictly necessarily in nuclear medicine.

With the scheme of Table I it becomes clear that reductionism cannot be the solution for dealing scientifically with the objects of the higher level. At the level of a human being or an animal, all will agree that, after a sufficiently long process of decomposition, one will end up with atoms or nuclear particles. This relates, however, only to the material principle of the substance in question. The formal principle that determines the arrangement of atoms and provides the strong unity, however, exceeds completely the formal principles of the underlying layers. In (Anderson 1972) it is argued that even in the realm of physics, systems composed of simple physical objects exhibit new phenomena that cannot be described without new concepts.

The role of the disciplines and the relation with the different levels in Table I is indicated in the last column. One should bear in mind that the list of disciplines in every level is not exhaustive, without perhaps the lowest two or three levels. At the higher levels complexity increases and only a multidisciplinary approach will result in real progress. Consider, for example, the case of a human artifact, the airplane. For the design and realization of a new generation of transatlantic jets a large group of specialists have to collaborate: materials scientists, physicists, all kind of engineers, safety specialists knowing the legal rules of the different countries, economists, artists for the design of the cabin, and so on. All these specialists use their own science and knowledge with their own concepts. Their intuition is needed to arrive at a "good" airplane. The quality "good" cannot be formalized as the optimizations proposed by the different disciplines are in a certain way contradictory. Safety requirements, for example, require mostly adaptations that lead to additional load during flight and lead therefore to less cost-effective solutions.

5. A tentative philosophy of complexity

In the forgoing the role of cognitive processes in human beings and the importance of intuition and the elaboration of concepts have been discussed. This has led to the proposal of a hierarchy in scientific disciplines on the basis of the analogy of being and the distinction between material and formal principles. Herewith the main building blocks are now available for a tentative philosophy of complexity. The starting point is the observation that in all levels of science there are things, beings or substances that have their wholeness or unity (*unum*): the whole is more than the sum of parts. The fact that we can and in fact do count protons, atoms, molecules, airplanes, cells, animals, human beings and nations indicate that common sense considers these as gifted with sufficient individuality. Molecules, e.g., in certain aspects form a unity that exceeds the pure geometric arrangement of the constituent atoms. For experiments that illustrate the relation of the whole and the parts one may refer to the discussion of the hydrogen atom and molecule in (Driessen 2015).

The different levels of beings form a hierarchy, as the higher beings can be reduced, at least regarding the material principles, to the lower beings. This hierarchy is not uniquely defined and may exhibit branches. The artifacts (the airplane in Table I) seem to follow a route different from the natural living beings. In all levels one should bear in mind that beings and substances are analogical terms. If there is a sufficiently strong formal reason to consider the unity of an object one can address it as a standalone being, a substance. That is not in contradiction to that in a different approach one focusses only on the individual constituent parts. A human being, for example, has a very strong unity, in fact the strongest in the material world. But considering the physics of x-ray absorption of a human thorax, only the distribution and characteristics of the individual atoms are relevant.

The distinction between organic and inorganic, living and non-living, natural or man-made beings or substances is more or less important, but does not lead to a different approach in the scheme of Table I. The unity is strongest in living beings which especially in the higher forms exhibit individual and, in the case of human beings, even personal characteristics. When ascending the hierarchy, beings are increasingly rich or complex with regard to the formal aspects. The information needed to understand the relevant concepts is rapidly increasing. The material aspects in a certain sense are participating in the increasing complexity. The constituent material parts of the beings of the higher levels are not low level beings. Only very strong violent causes may reduce, for example, a dog to the level of elementary particles. To do so, conventional means like burning, will not be sufficient. One needs the reaction of a nuclear bomb.

Aquinas already observed that the lowest level of material, the so-called *materia prima*, cannot receive straightforwardly the high-level forms. Instead a certain order has to be respected (Aquinas Metaphysics):

> Yet even though something is generated from that kind of non-being which is being in potentiality, still a thing is not generated from every kind of non-being, but different things come from different matters. For everything capable of being generated has a definite matter from which it comes to be, because there must be a proportion between form and matter. For even though first matter is in potentiality to all forms, it nevertheless receives them in a certain order. For first of all it is in potency to the forms of the elements, and through the intermediary of these, insofar as they are mixed in different proportions, it is in potency to different forms. Hence not everything can come to be directly from everything else unless perhaps by being resolved into first matter.

In a famous paragraph in the Summa contra Gentiles these ideas are worked out in more detail. Aquinas considers explicitly this gradation in forms and observes that complete beings, e.g. elements, can be considered as matter for complex bodies, which he called mixed bodies. In certain sense he is in agreement with modern biology and confirms biological evolution in as far as for him no new materials are needed to form plants, animals or even humans. The only novelty is the form of the higher level, the information that actualizes the suitable disposed matter. This high-level form is called soul according to the Aristotelian expression psyche. One has to bear in mind that in the current use of the language, 'soul' is restricted to the human soul, i.e. to persons. When Aristotle and Aquinas use psyche (soul) in connection with plants and trees they evidently do not attribute to them a personal character. In (Aquinas contra Gentiles) one can read:

> Now, among the acts pertaining to forms, certain gradations are found. Thus, prime matter is in potency, first of all, to the form of an element. When it is existing under the form of an element it is in potency to the form of a mixed body; that is why the elements are matter for the mixed body. Considered under the form of a mixed body, it is in potency to a vegetative soul, for this sort of soul is the act of a body. In turn, the vegetative soul is in potency to a sensitive soul, and a sensitive one to an intellectual one.

In the previous section emphasis was laid of the material aspects in the hierarchy of Table I. Now the focus is more on the formal aspects. In the high level beings the number of disciplines contributing to an adequate understanding is rapidly increasing. Only a multidisciplinary approach is able to tackle the large number of relevant phenomena. It is interesting to observe that especially in the artifacts non-technical issues are gaining importance. Ergonomics lead to user-friendly apparatus. Economic and legal arguments are often decisive when selecting which apparatus will be taken into production out of a number of technically possible solutions. Also ethical aspects enter, see for example our previous study related to optical communication (Driessen 2009). In the bio-industry new phenomena arise, as natural beings are manipulated to lead to improved 'natural' products. Also here non-technical issues are involved like: Which outer appearance of a tomato will attract buyers? Which taste is wanted by a certain group of people? Which legal measures should be taken to avoid serious environmental and health effects by uncontrolled genetic manipulation?

The characteristics of a complex system include emergence of new properties, as has been mentioned in section 2. In Table I it is shown explicitly that at all levels of the proposed hierarchy new concepts arise or emerge. Butterfield describes it as (Butterfield 2011):

> I take emergence as behaviour that is novel and robust relative to some comparison class.

The *comparison class* represents the elements that constitute the system at a higher level. Mittelstrass differentiates between strong and weak emergence. He refers explicitly to complex systems and provides the following definition (Mittelstrass 2014):

> Emergence says again that it is impossible to use characteristics of elements and the interrelations between these to describe characteristics of ensembles or make predictions about them. The core element of a *strong* emergence thesis is a non-derivability or non-explainability hypothesis of the system characteristics shaped from the characteristics of the system components. An emergent characteristic is non-derivable; its occurrence is in this sense unexpected and unpredictable. *Weak* emergence is limited to the difference of the characteristics of systems and system components and is compatible with the theoretical explainability of the system characteristics. Weak emergence in turn is essentially a phenomenon of complexity.

Butterfield (2011) comments in his paper on the *More is Different* slogan of (Anderson 1972) and shows that in many cases emergence and reductionism are compatible. It seems to be that this is exactly the case when one is dealing with *weak* emergence according to Mittelstrass. It is worthwhile to quote Butterfield in his paper *Less is Different* (2011):

> ‘More is different!’, proclaimed Philip Anderson in a famous paper (1972) advocating the autonomy of what are often called ‘special’ or ‘higher-level’ sciences or theories. A catchy slogan, indeed. But his reductionist opponents, such as Weinberg (1987), could have matched it (…). ‘Less is more’. Hence my title. For my main point will be that although emergence is usually opposed to reduction, many examples exhibit both. So my title, ‘Less is different’, is meant as an irenic combination of the two parties’ slogans.

The scientific study of the concepts at the higher levels in Table 1 , their generalizations and their relations may give rise to new disciplines. In a multidisciplinary project one of the greatest problems is the "language" of the different disciplines. This language is mainly based on well-established concepts in the individual discipline. Being able to understand the concepts without the ballast of the formalized discipline-related approach is one of the greatest challenges in such a collaboration. Once again it is stressed that the acquisition of the adequate concepts is largely based on intuition. The related 'Aha-Erlebnis' is not so much the result of a deep analysis as of a synthetic view.

If one agrees with the last statement that each level brings up really new concepts then the disciplines at each level have their fundamental aspects, i.e. on each level fundamental science is possible and needed. Fundamental science, therefore, is not restricted to certain fields of physics or other low-lying levels in the hierarchy of Table I. Even in artifacts, concepts may arise that need the academic environment to be understood and deepened in an adequate way. This scientific work eventually will acquire an applied character if the new knowledge is used for creating or manipulating things for a specific purpose. This view is not generally accepted as the ideal of any real science is for many scientists still the Cartesian *clare et distincte*. It is not a purely academic discussion, as the science curricula at High Schools and universities depend sensitively on the view on science. And, not to forget, the distribution of research money, too.

Within the scientific community some scientists adhere a similar opinion as given in the previous sections. The French Nobel-Prize winner Pierre-Gilles de Gennes complains about the prejudice of French culture, probably not restricted to that country (De Gennes 1994):

> I would now like to speak about a typical prejudice of the French culture, a prejudice inherited from Auguste Comte's positivism. This 19th century philosopher built up his glory by establishing a classification of sciences. At the top of the hierarchy, mathematics; at the bottom, chemistry which, according to him, "hardly deserves to be considered a science ”(!), in the middle, astronomy and physics. This classification excluded geography and mineralogy, sciences that he considered concrete and descriptive, thus keeping only theoretical, abstract and general sciences.

As mentioned above, P.W. Anderson published a similar hierarchy of disciplines as given in Table I and states (Anderson 1972):

> At each stage entirely new laws, concepts, and generalizations are necessary, requiring inspiration and creativity to just as great a degree as in the previous one.

At this point one could be satisfied with the result obtained. The hierarchy of Table I has been established and hopefully new insight has been enabled regarding the relation between the parts and the whole in a complex system. But it is common for children and philosophers to continue asking the question: why? In our case, why is there a hierarchy in beings, see Table I, why is there something like self-organization and emergence of properties. Mariano Artigas provides an attractive view that could lead to an answer (Artigas 2002):

> I used to say that information is "materialized rationality". It includes plans that are stored in spatio-temporal structures. It guides the successive formation of increasingly complex patterns. Information is stored, displayed, integrated, coded and decoded in the different natural systems and processes. (….)
> The corresponding idea of God is that of a Creator who has conceived the natural dynamism, and uses it to produce, according to the natural laws created by Him, a world of successive levels of emerging novelties.

This view is not new, already Aquinas explicitly considered this approach (Aquinas Physics):

> Nature is nothing other than the *ratio* of a certain art, namely, the divine, inscribed in things, by which things themselves move to a determinate end: just as if the master shipbuilder could impart to the wood something from which it could move itself to taking on the form of the ship.

Both, Artigas and Aquinas refer to rationality as the basis of the emergence of higher level beings. In main-stream biological evolution theory the term rationality is avoided and the term chance is used instead. One may consider this as is a matter of taste, as science on its own cannot distinguish between chance or rational intention (Driessen 2010). To make this distinction one has to leave the realm of natural science (Naturwissenschaften) and enter the realm of humanities (Geisteswissenschaften), more specifically the realm of metaphysics (meta-biology) or more general philosophy. It is philosophical reflection on the scientific results that allows this distinction. An example of this reflection on a meta-level in the line of the ideas of Aquinas and Artigas is presented by M. I. George (George 2008):

> The fact that random processes can result in living things arising from non-living things presupposes the existence of not just any sort of matter, but one which has the potency to be formed into living things; further, not just any sort of agents will do; but there must be ones apt to impart the appropriate forms to the appropriate matter. In addition, in order for these supposedly randomly formed living things to survive and reproduce, there must be a habitat favorable to them, and the possibility of its development also needs explanation. Just as it is luck that one gets a royal flush, but not that one can get it - the deck is designed that way, so too it may be luck that this or that organism appear, but it cannot be luck that it is able to appear.

It may be redundant, but once again it is important to stress that is a matter of taste. The scientific facts alone do not oblige to accept or refute the chance- nor the design-hypothesis. The aphorism of A. Suarez *Evolution is the smartest form of creation* (Suarez 2016) is a good summary of a clear choice: accepting all scientific results on evolution, accepting a rational creator but rejecting creationism.

6. Conclusions

Looking back to the previous sections one sees that most of the discussion has been in the field of philosophy. It is surely not suprising, as only philosophy can deal with the whole hierarchy of beings. More precisely, one can remark that without a metaphysical basis a discussion about the different disciplines is missing the common link. This leads to probably the most important conclusion that the acquisition of philosophical concepts and insight helps to clarify the complex relation between the different disciplines of science and helps to deal with complex scientific or technological problems.

A second conclusion is about the necessity to develop the capacity for scientific intuition. Success in a multidisciplinary setting is closely related to the understanding of the basic concepts of all disciplines involved. And this is only possible with a well-developed capacity for intuition. It is only on this basis that inspiration and creativity can push forward the scientific frontiers.

A third conclusion is that philosophy is a good school for developing the intuitive capacity of scientist as it is based on the subtle interplay of concepts in a logic system. One therefore should stimulate that philosophy be an integral part of the education at High School and Universities.

Finally one could remark that the occurrence of complex systems in nature and technology together with the emergence of new properties and laws is a non-trivial issue. For it relates to the big questions of science, specifically about the origin of information, and eventually to the question of the existence of God, see, e.g., (Carrol 2016) and (Tanzella-Nitti 2016).

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