PHILOSOPHY, NEUROSCIENCE, AND THE GIFT OF CREATIVITY

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Summary

The paper aims to connect three dimensions of scientific and philosophical research: the basic features of consciousness, the theory of knowledge, and the nature of human creativity. From a neuroscientific explanation of the mind we can obtain valuable considerations regarding the task of epistemology, the unity of reality, and the scope of creativity as the principal driver of human progress.

Keywords: consciousness, subjectivity, integration, creativity.

1. Towards a neuroscientific understanding of consciousness

Consciousness is no longer the «intractable»[1] mystery that had puzzled philosophers and scientists for centuries. Recent research has shown plausible ways of examining the subjective dimension of the human mind from an objective point of view. This progress raises hopes in identifying the exact mechanism underlying the phenomenon of consciousness, *id est*, the reflexivity of human experience.

In particular, the theoretical and experimental tools developed by modern neuroscience have unveiled vigorous strategies for a scientific study of consciousness. While the impossibility of establishing a causal link between subjective experience and its neural correlates had been assumed for decades –a deficiency that left room for philosophical notions like «intentionality», as opposed to causality–, compelling evidence suggests that it is indeed viable for science to address the precise way in which the neurobiological structure of the nervous system is capable of generating conscious phenomena.[2]

[1] «Consciousness is what makes the mind-body problem really intractable» (T. Nagel, «What is it like to be a bat?», *The philosophical review* 83/4 (1974), 435.

[2] Cf. S. Dehaene – J.P. Changeux, «Experimental and theoretical approaches to conscious processing», *Neuron* 70/2 (2011), 200-227.

These empirical tests include experiments contrasting visible and invisible stimuli («a visual stimulus that is masked and remains invisible can nevertheless affect behavior and brain activity at multiple levels»)[3], or, more generally, perceived and unperceived stimuli in different sensory modalities, like subliminal priming and the use of brain-scale neuroimaging. These experiments help us understand what happens in the brain when, for example, the subject is exposed to a visible *versus* invisible word or a detected *versus* a non-detected sound.

The study of how the brain processes masked *versus* unmasked stimuli has also shown the relevance of the high-frequency fluctuations (especially in the gamma band -30-40 Hz-)[4] and of phase synchronization across distant cortical regions[5] when conscious perception occurs. This set of data points to a phenomenon that was highlighted by Sir Francis Crick: consciousness is most probably related to the synchronization of different brain regions. Long-distance phase-synchrony can be understood as the simultaneous activation of both perceptual areas and associative areas. Broadly speaking, if perceptual areas provide bottom-up information, associative areas offer top-down information whose integration yields conscious perception. Of course, this is a simplification of a uniquely complex process, and its details remain largely unsolved, but both from a philosophical and a neuroscientific perspective it is legitimate to understand consciousness as assimilated information that reverts on the subject (therefore, as information both assimilated and judged by the subject).

Also, the study of certain anatomical structures in charge of linking perceptual areas (like the occipital lobe) with prefrontal, associative areas may shed valuable light on the nature of consciousness. If consciousness involves the subjective assimilation of information, it is reasonable to think that those structures whose mission consists of connecting posterior and anterior regions of the brain will play an important role in this process. In particular, an interesting anatomical structure is the superior longitudinal fasciculus.

The research of authors like Gerald Edelman, Giulio Tononi, Stanislas Dehaene, and Jean-Pierre Changeux has highlighted that any theory of consciousness must at least consider the following explanatory elements:[6]

1. A supervision system: hierarchically organized, higher levels control the functioning of lower levels, and lower levels «report» to higher levels, so that in this unending interaction which works both top-down and bottom-up, a deep and successful division of labor takes place. The higher levels are associated with the prefrontal cortex,[7] while the lower levels imply

[3] *Op. cit.*, 202.

[4] However, recent studies show that these oscillations can also exist in anaesthetized patients.

[5] S.M. Doesburg – J.J. Green – L.M. Ward, «Rhythms of consciousness: binocular rivalry reveals large-scale oscillatory network dynamics mediating visual perception», *PloS one*, 4/7 (2009), e6142.

[6] Cf. S. Dehaene – J.P. Changeux, «Experimental and theoretical approaches to conscious processing», *Neuron* 70/2 (2011), 210.

[7] Although the reticular activation system does not generate consciousness *per se*, there is strong evidence to support that it plays a fundamental role in keeping a state of consciousness.

the participation of different cortical regions.

2. A serial processing system: consciousness works through discrimination of stimuli. This capacity to select the information that is valuable for the subject at a certain time is an outstanding feature of conscious experience, and it is related to the idea of attention. We also know that this serial processing system coexists with a parallel system of information processing, which is particularly visible when we analyze higher cognitive functions like memory[8] (some authors have proposed that the parallel system is essentially non-conscious,[9] while conscious access is serial).

3. A coherent assembly of re-entrant or top-down loops: reafference involves the presence of a constant feedback system that benefits from afferent information to generate efferent information. This bidirectionality constitutes a fundamental, fertile feature of the mind, because it dilutes the necessity of a central, ultimate core of conscious perception. Subjectivity will reside in the constant exchange of information between the environment and the internal architecture of the nervous system; although some structures enjoy a privileged, hierarchical position, the decision core is shared by all the regions involved in the assimilation of information to make it consciously perceived. The unification that is characteristic of human consciousness (the fact that, instead of perceiving isolated features of the stimulus in a separate way, I grasp the stimulus as a unitary whole) is guaranteed by the presence of re-entrant circuits that are constantly processing information and receiving feedbacks from past memories.

Several problems remain, of course. For example, the so-called problem of *qualia*, that has generated such a vivid debate throughout the history of philosophy. However, it is not utopian to think that, as our knowledge of sensory system increases and we are capable of understanding how the brain functions as a whole, the perception of secondary qualities will yield to a scientific explanation in terms of neurons, synapses, and neural circuits. And, in the future, there is no *a priori* reason to exclude the viability of reproducing subjective feelings of taste, color, sound, and similar properties in an artificial machine that will allow us to experience alien subjective feelings, because if we understand the intimate mechanisms of a system, sooner or later it will be susceptible to artificial reconstruction.

The brain reconstructs reality. This is clearly perceptible in the study of the visual system, one of the greatest intellectual achievements of the 20th century.[10] The work of David Hubel and Torsten Wiesel has shown the fine degree of specialization acquired by the columns of the different layers of the visual cortex. This confirms –at

[8] I have discussed this with certain degree of depth in *Historia de la neurociencia. El conocimiento del cerebro y la mente desde una perspectiva interdisciplinaria*, Madrid, Biblioteca Nueva, 2014, 181-211.

[9] Cf. H. Pashler, «Dual-task interference in simple tasks: data and theory», *Psychological bulletin*, 116/2 (1994), 220.

[10] For a comprehensive study of the visual system, see S.M. Zeki, *A Vision of the Brain*, Oxford, Blackwell Scientific Publications, 1993.

least analogically– Kant's intuition that, against naïve realism, we do not directly reproduce reality, but we rebuild it according to the inner structure of our mental device. And the most striking proof of this process of reconstruction resides in the possibility of reducing a 3-dimensional reality into a 2-dimensional reality without losing significant information. The brain already «knew» this from the beginning, because the retina is capable of transforming 3d information into 2d information. Modern physics has discovered, in fact, that no information is lost in passing from 3d to 2d (an outstanding feature that has inspired highly speculative hypotheses like the famous «holographic principle»)[11].

In any case, the deepest theoretical challenge is still related to the idea of subjectivity; not so much in its dimension of subjective experience but in its condition of agency. It is extremely hard to develop any meaningful philosophical discourse without the presupposition that there is a *subjective core* in charge of activating the whole mental machinery. The *I* that decides, the *I* that feels, the *I* that thinks… acts as some sort of «pontiff» in the brain, as an unmoved prime mover, without whose assumption the functioning of the mind would be deprived of its intrinsic unity. Behold the difficulty to escape the problem of a decision-making center (the mystery of agency, of the *I* as a regulatory idea, in Kantian terms). The participation of prefrontal cortex in decision-making processes is well documented[12], but we need to analyze how every cerebral system processes information and we have to reconstruct the dynamics of neural groups, for the nervous system exhibits a powerful «integrative action», as Sir Charles Sherrington proposed more than a century ago.

The capacity of mind to unify external stimuli into a coherent, unitary perception of which the subject can become conscious is one of its most astonishing features, and it is still waiting for a scientific, mechanistic explanation. But we can hope that future neuroscientific research will allow us to grasp the profoundest intimacies of the workings of the human mind. In particular, the problem of the *I* (or, in analogous terms, of Sherrington's «pontifical neuron»), can be gradually dissolved if we understand that the integrative action of the mind never resolves into a final instance of decision; rather, it consists of a continuous system of reentrant signals and circuits functioning in parallel that dispenses with the necessity of attributing the final word to a subjective core.

Among the most promising theoretical frameworks to explain subjectivity in an objective way, I want to highlight three of them. The first one is the dynamic core hypothesis. Attributed to Tononi and

[11] According to the Bekenstein-Hawking equation, in a black hole, entropy –a magnitude closely related to information– is proportional to the area, not to the volume, as it could have been expected. On the relationship between holography and cosmology, see G.T. Hooft, «The Holographic Principle Opening Lecture», in *Basics and Highlights in Fundamental Physics* 37 (2001), 72.

[12] Cf. Frith, C. D., Friston, K. J., Liddle, P. F., & Frackowiak, R. S. J. (1991). Willed action and the prefrontal cortex in man: a study with PET. *Proceedings of the Royal Society of London B: Biological Sciences*, *244*(1311), 241-246.

Edelman,[13] it interprets consciousness as integrated information. A magnitude called *fi* (ϕ) measures the degree of integration that information is experiencing. High values of *fi* imply that a certain piece of information is not only differentiated from another but also that it has been achieved through a recurrent, hierarchical connectivity.

This model, however illuminating, poses some problems. In particular, a purely phenomenological depiction of consciousness shows that this property is not only a matter of integration but of separation: the subject is conscious of a unified perception because he is capable of judging it as an external observer.

Strongly connected with the dynamic core hypothesis is Edelman's «Neural Darwinism». According to Edelman, a neural substrate of consciousness comprises large neuronal populations –particularly in the thalamo-cortical system-, broadly distributed throughout the whole brain. In his view, no specific area of the brain is entirely responsible for conscious activity.

One of the fundamental tenets of this hypothesis states (in analogy with immunological processes) that the brain works through a mechanism of selection. Anatomical connectivity in the nervous system would obey a process of Darwinian selection during its epigenetic development. The primary repertoire of connections, if useful for the individual, would be susceptible to replication. In a second process of selection, the experience accumulated by the subject would propitiate the establishment of the most favorable synaptic connections. This secondary repertoire would be subject to differential reproduction. Of course, a key idea points to degenerate states: different neural groups can fulfill the same functions, so that consciousness is not located in a specific cerebral area. Through reentrant systems and a feedback mechanism, the famous «homunculus problem» (the tacit assumption that there is an ultimate «subject», or unmoved prime mover, inside the brain) is dissolved, because consciousness would consist of a constant interaction between the systems of neural connections and the environment, in a reciprocal exchange between the individual and the world.

One of the principal virtues of this hypothesis resides in its capacity to propose specific neurobiological mechanisms for consciousness. Based upon reentrant systems and epigenetic development, the brain creates both external categories (that apprehend the organization of reality) and internal categories (referred to the perception of ourselves). This capacity to categorize reality in its multiple dimensions stands as the great power of the mind.

However, some reasonable objections could be posed to this model:

1. The unity of replication: even if groups vary significantly, we can still delimitate cerebral areas in which specific functions are located (for example, areas in charge of processing language). Therefore, the controversy between localizationism and anti-localizationism (or «integrationism», according to

[13] Cf. G. Tononi – O. Sporns – G.M. Edelman, «Reentry and the problem of integrating multiple cortical areas: simulation of dynamic integration in the visual system», *Cerebral Cortex*, 2/4 (1992), 310-335; G. Tononi – G.M. Edelman, «Consciousness and complexity», *Science* 282 (1998), 1846-1851.

which all regions of the brain are equipotential regarding higher functionality) cannot be solved by favoring one of the terms of the binomial, because there is compelling evidence that some functions are strictly associated with concrete cerebral areas: consciousness works both through differentiation and integration. Even if there is an astonishing degree of versatility in each neural group, we still have areas with constrained functions, and we can state that the brain works through a fertile division of labor among its regions. Of course, the problem of how each area knows the task that it has to perform implies the question about the «central program» of the brain and a core decision center at the highest organizational level, but in this hierarchy of functions it cannot be denied that some processes are inextricably related to some areas instead of others.

2. There is no real theoretical incompatibility between Edelman's neural Darwinism and the computational model of mind. The brain could be a machine that optimizes available information about the environment and its own inner structure[14], endowed with a program of instructions genetically transmitted, quite similar to Chomsky's idea of an innate capacity to learn any language before actual linguistic stimuli have appeared. Although Edelman is critical of applying computational models to the human mind (which he views as an essentially biological process), it is suspicious that he continuously employs terms of computational resonances, like «input», «output»… In fact, the creation of machines capable of «learning to learn», instead of simply following a set of instructions, is one of the greatest technological revolutions of the last years, and it is called to revolutionize our understanding of artificial intelligence.[15] Even if the brain works as a computer, this does not mean that it is a computer. The brain can possess a minimum, highly elastic set of instructions which grant it its wonderful plasticity and its fascinating capacity to learn.

3. Which are the selective criteria used by the brain, if it cannot know *ex ante* whether its strategies will lead to survival? In the case of the evolution of species, the dilemma is solved *ex post*: through the elimination of less favored forms and the survival of the fittest. But in Edelman's model, it is not clear how we could apply this rule, because there is no real reproduction *versus* elimination mechanism. Instead of employing the concept of selection, wouldn't it be more legitimate to evoke an idea of progressive coupling between the inner structures and systems of the brain and the reality that it is processing (through higher degrees of fine-tuning between the brain and the world), so that those neural circuits that better replicate reality and offer more valuable information about both the inner and external environment will be favored? The reality is that we cannot be sure

[14] Cf. A. Clark, «Whatever next? Predictive brains, situated agents, and the future of cognitive science», *Behavioral and Brain Sciences*, 36/3 (2013), 181-204.

[15] The case of «Google Deep Mind», whose artificial neural network is capable of learning to play videogames with extreme proficiency (their AlphaGo program has recently managed to beat a professional «Go» player) in a way that resembles human beings, is a clear example of this trend.

of whether the unity of evolution is the neural group, because we know that the size of the brain (and the number of its neurons) is what has evolved through natural history.

The third model that I want to mention has been named «The Global Neuronal Workspace».[16] Their authors define it in the following way: «A subset of cortical pyramidal cells with long-range excitatory axons, particularly dense in prefrontal, cingulate, and parietal regions, together with the relevant thalamocortical loops, form a horizontal «neuronal workspace» interconnecting the multiple specialized, automatic, and non-conscious processors».[17]

The advantage of this model resides in its ability to integrate both the conscious and the unconscious into a coherent theory of conscious access. However, sometimes it seems too broad in its statements, and, as anyone knows, «the devil is in the details». But it is probably the most promising theoretical model developed to offer a scientific, mechanistic explanation of the phenomenon of consciousness and the different elements that converge into it. Also, it has clear anatomical implications and it is susceptible to specific predictions that can be experimentally tested. And, from a purely theoretical perspective, it is capable of assimilating the fundamental features of consciousness: high-level supervision, serial processing, re-entrant loops and the global availability of information, connected with specific proposals regarding the neuronal architecture of the process.

2. Philosophy and the unity of nature

Philosophy can help clarify the epistemological basis of neuroscientific theories, and it can contribute to the critique of some unjustified conclusions. It can also pose stimulating questions, capable of fostering scientific discussion. But the explanation of consciousness can only be achieved through a neurobiological mechanism, as Sir Francis Crick envisioned.

The elaboration of a theory of science is one of the fundamental tasks of philosophy. This intellectual pursuit has to explain how we acquire a kind of knowledge which can be regarded as «scientific». In the case of self-justified sciences, like logic and mathematics, the problem converges with determining the foundations of their axiomatic systems. But concerning the natural sciences, the difficulty lies in explaining the nature of scientific knowledge as such.

The general development of science can be understood in the light of a twofold schema. In analogy with evolutionary mechanisms, we have, on the one hand, the variation pole; on the other hand, the selection pole. Variation can be seen as the fruit of the free creations of the human spirit, as Einstein thought. We can find at least two modalities of variation: active variation (which stems from the genuine curiosity that moves the scientist into research) and reactive variation (elicited by a specific problem, a certain experiment, a newly discovered phenomenon in search of an explanation…).

[16] Cf. J.P. Changeux – S. Dehaene, «The neuronal workspace model: Conscious processing and learning», *Learning theory and behavior* 1 (2008), 729-758.

[17] Cf. Cf. S. Dehaene – J.P. Changeux, «Experimental and theoretical approaches to conscious processing», *Neuron* 70/2 (2011), 210.

Regarding selection, we can also distinguish internal means of selection (arising, for example, from the inconsistencies of a certain theory) and external means of selection (such as experimental contrast, which validates or refutes a theory in a limited context).

But what is a scientific explanation? Any explanation that aspires to transcend the level of a mere description is based upon the elucidation of a mechanism, that is to say, a sequence of steps mediating between an initial and a final state. Explaining a natural phenomenon consists of unveiling the underlying mechanism. Ideally, any scientific explanation should be capable of offering the prolix itinerary of energetic exchanges that mediate between the beginning (arbitrarily rifted) and the end (arbitrarily rifted) of a process. As incontestable principles we find the fundamental laws of nature (the conformity of nature to herself, as Newton realized): how nature manifests herself to us in an irreducible, axiomatic way, as unmoved prime epistemological mover. Science has only unveiled a mechanism once it has been able to articulate a sequence of steps that suffices to give reason of the current state, empirically observed.

Hence, the task of science resides in providing testable explanations of natural phenomena.[18] Any convincing explanation involves necessary and sufficient elements which delineate the mechanism of a specific phenomenon. Logically, this elucidation, aimed at remarking a plausible mechanism that shows the sufficient steps for understanding a given phenomenon, must shed light, not obscurity. The famous rejection of *obscurum per obscurius* (or analogous principles, like *ignotum per aeque ignotum*) expresses the reluctance to accepting even more improbable explanations of a certain phenomenon. Of course, the criterion of theoretical correction cannot be the simplicity, the clarity, or the beauty of an explanation, but its conformity to facts (its *truth*). However, when our knowledge of truth is too obscure, a criterion inspired in methodological parsimony exhorts us to proceed through that which is clear and proximate, not opaque and distant.

The mind is the most conspicuous phenomenon of nature for which we lack a fully satisfactory explanation. In any domain of science, new mysteries can always emerge and new theories can debunk older models. But in the case of the human mind, the level of our lack of understanding is much severer than in other spheres of scien-

[18] I have deliberately avoided the use of the term «falsifiability» because, in my view, Popper's approach does not explain how science really works. If I have not falsified a theory in one of its potential domains (meaning that I have not been able to disprove that particular prediction), I can say that I have verified it in that domain. For example, let us take Rayleigh-Jeans' law for the electromagnetic radiation of a black body at a given temperature. This law has not been falsified for high wavelengths (or low frequencies); therefore, it has been verified in those wavelengths. Of course, we know that it has been falsified in the range of low wavelengths, but this does not confute the fact that it has been verified in the range of high wavelengths, at least if we assume a fundamental isomorphy: that nature shows the same behavior with the same elements under the same conditions (otherwise, it would be difficult to conceive of the possibility of science itself, if no extrapolation from a given spatial and temporal domain to an equivalent, yet different spatial and temporal domain, could ever be achieved). In the case of Planck's law, we find that it has not been falsified in any domain of the electromagnetic spectrum. Thus, we can also state that it has been verified in all *known* ranges of the electromagnetic spectrum.

tific inquiry, like particle physics or cosmology. Just as physicists do not always agree on how to understand matter, or biologists on how to interpret life, neuroscientists and philosophers often discuss what consciousness is. But unlike physical or chemical problems, we can be pretty sure that the human mind is a much more complex system, and therefore it is more difficult that it may yield to a full explanation. However, this obscurity does not justify some sort of premature recreation, as if it left room for fortresses of philosophical reflection which will constantly resist the pressure of the natural sciences. No single natural phenomenon is free of the shadow of the unexplained. Science does not exhaust our understanding of reality but it facilitates it and broadens its scope. Therefore, to take pride in the inexplicability of the human mind not only does not contribute to the progress of knowledge but it sins from worrying philosophical ingenuity.

If the obscure should not be explained through the obscurer, any study of mind as a natural phenomenon must respect scientific evidence. This submission to accumulated evidence does not oblige us to renounce a critical spirit. New evidence will come that may relativize our present knowledge. Nevertheless, the facts that we have, almost universally accepted, cannot be disdained, and it is reasonable and parsimonious from the point of view of reason and empirical evidence to harmoniously integrate these facts into a broader frame.

Which are the facts?

1. First of all, we have the strong evidence that the most admirable and astonishing mental faculties of the human being are dependent upon a series of neurobiological structures, susceptible to delimitation. It is certainly possible that other physical structures (like silicon) be capable of hosting analogous functions, but if we constrain our analysis to the human mind, there is an inextricable connection between the development of cerebral cortex and the acquisition of our most conspicuous cognitive abilities.

2. Biology possesses a wonderful explanatory tool, whose efficacy, if not in all the details, is at least visible in the general panoramic about the birth of these formidable mental abilities that bless the *Homo sapiens*: the theory of evolution. We can –fruitfully or uselessly– argue about the deficiencies of the theory of evolution in its current shape, but any attempt at explaining the workings of the mind needs to respect the evidence that builds our biological knowledge. And this evidence points to a gradual rising of the human mind, in a process of increasing complexity from simpler biological forms. For example, we know that the development of higher cognitive functions in the human species is intimately associated with the extraordinary expansion of the prefrontal cortex throughout mammalian evolution. If, in terms of its cytoarchitecture, for a lemur the prefrontal cortex represents 8'5% of the total volume of its cortex, the number increases to 11'5% in the case of gibbon and macaque, to 17'5% in the chimpanzee, and to 29% in *Homo sapiens.*[19]

[19] Cf. J. Fuster, *The Neuroscience of Freedom and Creativity*, Cambridge,Cambridge University Press, 2013, 33, note 3.

Even if other facts endowed with a similar degree of verisimilitude could be added, the two elements of analysis that we have just mentioned must appear in any scientific and philosophical explanation of the human mind.

From a purely philosophical perspective it can be peacefully accepted that there is a logical and ontological continuity between the objects of study of philosophy and the natural sciences. The fragmentation of the different areas of knowledge obeys practical, not fundamental reasons, because the deeper our understanding of the structure and functioning of the world becomes, the easier it is for us to perceive the profound continuity that binds all spheres and objects of nature. Great theoretical frameworks, like quantum physics (capable of uniting microscopic physics and chemistry) and the theory of evolution (that offers a unitary perspective about all biological phenomena from the point of view of their natural history and the modifications that have been successively acquired), have allowed us to appreciate more clearly this intimate connection between all the objects and processes of the natural world. Because the human mind can always conceive of an object –or a sum of objects– as a unitary whole, there are no aprioristic reasons forbidding us to consider the totality of phenomena susceptible to analysis as a vast *continuum*, apprehended through identical logical parameters. It is the task of a theory of knowledge to elucidate them and to provide both philosophy and the natural sciences with a unifying global frame.

The reduction of higher cognitive functions to a neurobiological explanation (that ultimately involves a physical-chemical explanation) should not be regarded as a threat to both philosophy and the humanities. The scientific elucidation of the nature of consciousness does not diminish its wonder and importance. On the contrary, it allows us to acknowledge the extraordinary power of human intelligence and it opens new, unforeseen scenarios regarding the true capabilities of this most astonishing gift that we have received from millions of years of evolutionary history.

Although ontologically all pieces of evidence point to a strict naturalism regarding the constitution of mind, this does not imply that the subjectivity of the individual may be entirely reproducible. The reason for this is the following: the mind, even if it consists of the functionality of the brain and it therefore represents a complex material entity, is built up of an almost infinite number of particular experiences in space and time which radically limit the possibility of reproducing all dimensions of subjectivity. The individual is constantly creating herself through her interaction with the environment and linguistic communication, a tool that multiplies exponentially the possibilities of recombining the elements of our thought. This is the pillar of our uniqueness. From this point of view, and although no true novelty can arise in the universe –at least in the domains of matter–, because every new phenomenon can be contemplated as the reconfiguration of previous phenomena and the total amount of energy in the universe is conserved, time adds real novelty, for every new instant necessarily differs from the past. The human being, through thinking and language, is endowed with the extraordinary

capability of taking the greatest advantage of the unrepeatability of time, by continuously inventing himself (actually, this is a feature pertaining all living entities, but it becomes dramatically important in *Homo sapiens*). It is in virtue of time and the scope of novelty generated by the existence of the second law of Thermodynamics (undoubtedly, one of the deepest and philosophically most fascinating mysteries of the physical sciences) that the human being is unceasingly creating himself and broadening the sphere of the material elements that compose him.

Unveiling the mechanisms of consciousness does not exhaust the range of its possibilities. Rather, it helps us appreciate the unity of nature, the unity of knowledge, and the unity of the scientific method[20], so that, beyond the apparent complexity of the universe and its elements, we can contemplate the profound simplicity of its fundamental laws. It is admirable indeed to realize how nature, in the course of evolution, has not needed to innovate significantly in the realm of the basic structures and processes that constitute biological entities. For example, the essential physical-chemical mechanisms that operate in the nervous system, like the sodium-potassium pump, are known to exist in more elementary biological structures. Nature seems to favor simplicity and economy, so that, through sophisticated combinatorial strategies, the most complex phenomena can be accomplished through the simplest mechanisms. Although we tend to highlight –legitimately– the innovative power of evolution to produce structures of outstanding heterogeneity and versatility, we sometimes forget that the great majority of biological phenomena obey relatively simple laws. As Newton famously wrote, «Nature is pleased with simplicity, and affects not the pomp of superfluous causes».[21]

3. Knowledge, creativity, and the future of humanity

It is hard to think of any great transformation in human history which has not been fueled by knowledge. Thanks to a deeper knowledge of material processes, humanity has been capable of increasing its power over the different forms of energy available in nature.

Of course, the history of human progress obeys a feedback mechanism between knowledge and material development (that ultimately consists of our capacity to exploit the different manifestations of energy). Sometimes, rational inquiry has led humanity to discover new forms of energy; in other occasions, the development of material forces has propitiated a dramatic increase in our possibility to expand knowledge. The level of development of a culture can in fact be easily summarized as the result of the information that is available at a given time. However, information (I, which can be viewed as the inverse of entropy) is the product of at least two functions: physical energy (E) and knowledge (K). In highly simplified terms, the synthesis of energetic efficiency and cognitive status

[20] Cf. C. Blanco, «The Integration of Knowledge», *Cadmus* (2016), 111.

[21] First rule of reasoning in natural philosophy, *Philosophiae Naturalis Principia Mathematica.*

marks the level of information that is available for a certain social group.

On the side of material development, it is clear that the great technological revolutions are dependent upon the discovery of new forms of energy that can be efficiently used by humanity. The industrial revolution is probably the best example of this tendency, which increased significantly variables like population, life expectancy, and average productivity. But in some relevant cases, purely cognitive revolutions have shaped the way in which humanity understands itself and have propitiated an unprecedented chain of intellectual and social changes. The work of Copernicus, Darwin, and Wallace shows the huge power that the advancement of knowledge can bring to liberate humanity from prejudices and dogmas in its quest for truth.

Knowledge can be reached through analysis, meaning the discovery of how nature works in its most basic elements. The analytic mind is keen on understanding the mechanisms of nature. It fragments reality as a way to elucidate its fundamental patterns. Although it gains in rigor and efficiency, it can also diminish the quality of our perspective. A synthetic mind, on the contrary, is prepared to unify the different elements of reality and the various branches of knowledge to achieve an interdisciplinary account of reality, but it can lead to broad generalizations, detached from the deep understanding of the fine structure of reality.

Given the number and scope of the challenges that humanity is facing (environmental degradation, social inequality, the rise of religious and ideological fanaticism, the lack of a unified social theory, the limits of current economic models, the difficulties in defining universal ethics…), it is clear that we should not underestimate any cognitive resource capable of increasing our power of understanding. We need analytic minds, synthetic minds and, moreover, imaginative minds. The overcoming of any given context and conceptual system will only be achieved if analytic power is combined with intuition, the gate to creativity. If we only look for analytic certainty, we will easily fall captives to intellectual inertia and we will not make the effort to build new paradigms that can expand and refine our understanding of reality. Courage to critically examine the premises and frames of reference with which the mind is working demands the collaboration of faculties like intuition, imagination, and synthetic gifts which are not always present in our purely analytic enterprises. Logic is the expression of rationality: a set of premises and transformation rules that allow us to go from one statement into another. Imagination, even if not illogical, obeys analogy, the creative establishment of connections and similarities which cannot be –at least immediately- proven in a sequential manner.

The overcoming of a mental framework needs to take into account the limits and contradictions of our systems of thought. Only if we become aware of the presuppositions of our conceptual guidelines can we aspire to improve our understanding of nature, society, and subjectivity, to reconcile views that nowadays seem impossible to harmonize.

There is no perfect conceptual system, and it is clear that the so-called «theory of

everything» of which some physicists dream cannot mean to eradicate the traces of contingency, creativity, and indeterminacy that prevail in several domains of reality. The first reason is that our knowledge of nature is always constrained. For example, until the 20th century, physicists thought that two fundamental forces sufficed to explain material processes. Today, we are aware of the necessity of at least four fundamental forces to understand the universe. The second reason points to the limits in our capacity to know and think that have been discovered by science itself. The two fundamental borders in our knowledge are Gödel's incompleteness theorems and Heisenberg's uncertainty principle. The first raises an analytic limit[22], referred to the inner structure of logical thinking, while the second poses a synthetic barrier to knowledge[23]. It is inevitable to speculate whether a much superior mind would be subject to Gödel's prohibition or to Heisenberg's restriction. Would a divine-like entity find its knowledge restricted by these boundaries, or it would be blessed with some sort of «higher rationality» –capable of avoiding Gödel's theorems– and with a deeper understanding of nature, capable of surmounting Heisenberg's indeterminacy? We do not know, and we do not know whether we will ever be able to answer this question. In any case, logical and physical evidence underlines the existence of at least two fundamental limits for human knowledge.

We cannot anticipate what surprises the study of matter and mind will bring to the intellectual enterprise of humanity. But ambiguity and ignorance are roads to progress. Only if we feel unsatisfied with the current paradigms and if we suffer the burden of ignorance about so many mysteries that attract our attention can we aim to advance.

Creativity is the hidden resource of humanity. Hidden, because it cannot be easily reduced to an algorithm, to a general rule, to a recipe; resource, because the great achievements of the human longing for knowledge and material improvement are the fruits of creativity.

Neuroscientific research has contributed to unveiling some neuroanatomical structures related with creativity. We know that the most relevant neural circuits belong to the prefrontal cortex, a cerebral area in charge of higher cognitive functions. The prefrontal cortex assumes the task of executive control over different cortical and subcortical structures. A key evolutionary development has generated the longitudinal superior fasciculus, an organ that connects the posterior cortex and the prefrontal cortex. This marvelous integration of both perceptual areas and executive areas had to be favored by natural selection and epigenetic development, because it offered the

[22] Gödel's two theorems state that no consistent system of axioms whose theorems can be formalized in an effective procedure is capable of proving all the truths about the arithmetic of natural numbers; in any such formal system there will always exist statements that are true, but unprovable. Also, the system cannot prove its own consistency (cf. K. Gödel, «Über formal unentscheidbare Sätze der *Principia Mathematica* und verwandter Systeme I», *Monatshefte für Mathematik und Physik* 38/1 (1931), 173-198).

[23] «It is impossible to know with absolute accuracy and in a simultaneous manner two canonically conjugated magnitudes, like the position and momentum of a particle» (cf. H. Heisenberg, «Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik», *Zeitschrift für Physik* 43/3-4 (1927), 172-198).

advantage of building a mind that, instead of passively assimilating perceptual stimuli, could exert an active control over them.[24]

Even if creativity cannot be subject to a mechanistic, sequential understanding, at least it can be described as the combination of two factors: variation and selection. How the creative mind works does not significantly differ from how nature works. There is always an uncontrolled, «chaotic», variable element in creativity. However, true creativity (meaning a form of creativity that can be useful in any manner) requires a selective filtering of the imaginative expansion that characterizes the first factor. Creative freedom needs to be structured by an ordaining element, which selects the possibilities unveiled by imagination through a unifying rule, capable of bringing harmony and turning chaotic exuberance into a fertile creation. Useful creativity stems from the integration of both the overwhelming, untamable power of imagination (whose preeminent manifestation in *Homo sapiens* lies in the gift of symbolic thinking, because it establishes an element of mediation between reference and meaning; thus, it multiplies the possibilities of creating analogies and second-order languages) and the selective filter of acquired knowledge and social demands.

Imagination and knowledge of the present status of a certain discipline or human dimension, if rightly matched, underlie the great triumphs of human creativity. The individual has to become familiar with the great advancements of the past, but she has to avoid the uncritical assumption of inherited opinions if she really wants to make a relevant contribution. Sadly, this aspiration is severely limited by the constraints of a rigid educational system, where the transmission of facts, ideas, and discoveries generally obeys a dangerous illusion of immutability, in which the most relevant elements of learning are not always taught dynamically, by helping develop an appetite for knowledge and a critical mind that allow us to understand how these facts, ideas, and discoveries were actually achieved and can be expanded.

The acquisition of knowledge is probably the greatest ethical tool of humanity, because in the individual's longing for knowledge, an open mind and a humble spirit stand as the necessary steps. This relativization of one's own assumptions and this recognition of one's own ignorance is certainly the first stage in building a more tolerant world. And knowledge, beyond ethical consequences, manifests a profound aesthetic dimension: the experience of the elegance and harmony of the truths that the sciences unveil about how the universe works and how, from simplicity, unimaginable complexity can emerge.

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[24] Cf. J. Fuster, *The Neuroscience of Freedom and Creativity*, Cambridge University Press, Cambridge 2013, 33ss. The study of emotions has also shed valuable light on the functioning of human creativity. Cf. A. Damasio, *Self Comes to Mind: Constructing the Conscious Brain*, London, Vintage, 2012.