World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(REVIEW ARTICLE)

Check for updates

Communication as an evolutionary factor of knowledge, from primordial organisms to complex collective systems

Bruno Riccardi [1,*], Sergio Resta [2] and Giacomo Resta [3]

[1] *Biologist freelancer, 56022 Castelfranco di Sotto (Pisa), Via dei lazzeri, 33, Italy.*
[2] *General Surgery Specialist, Freelancer, 53043 Chiusi (SI) – Via Monte Grappa, Italy.*
[3] *Pharmacy student, University of Perugia, Italy.*

World Journal of Advanced Research and Reviews, 2023, 20(01), 1210–1220

Publication history: Received on 13 September 2023; revised on 24 October 2023; accepted on 26 October 2023

Article DOI: https://doi.org/10.30574/wjarr.2023.20.1.2159

Abstract

The intrinsic characteristic of material substances is their ability to modify their physical state and their energy content in response to the interactions and stresses they receive.

And it is the capacity that crosses transversely all living matter including man, with the difference that the man solicited by external events becomes aware of his own uniqueness and his own destiny.

We can say that man acquires human characters when he learns to re-know his fellow men and the world around him and experiences the wonder that this experience transmits him.

And we will show how the whole of the multiplication of contacts and interactions between men produces the corpus of knowledge of peoples.

Starting from this hypothesis, in this work we are going to describe how the transformations produced by the reciprocal interactions between material substances, and between these and their environment, are acquired in the form of knowledge.

The analysis of the events we describe of the cognitive process follows the logical procedure, which will lead us to the conclusion that knowledge is the intrinsic manifestation of matter and how it originates and takes shape from it. With the advent of man, the highest expression of the organization of matter and knowledge, matter itself embodied in man can investigate knowing itself and its intimate essence.

Thus, knowledge can be conceived as the virtuous ontological circuit that originates from matter and returns to it modified in form and enriched with content.

Keywords: Communication; Molecular interaction; Knowledge; Quantum interaction; Receptors systems

1. Introduction

The objective of this work is to explain knowledge in a mechanistic key as an elementary phenomenon of interaction that takes place between material bodies, and as the effect that such interaction determines on the physical state of the bodies and the time/space that contains them.

* Corresponding author: Bruno Riccardi.

Thus, knowledge means the complex of processes by which material bodies interact with each other and with the environment, modify their original state and preserve the new state.

Thus, knowledge presupposes the presence of material elements that can produce mutually perceptible and adjustable modifications of their state, in a defined space-time context.

In all the texts of general linguistics the communication process is described as the activity that requires the presence of six factors, representing the six different operational functions of communication [1-3] We can outline them graphically in the following figure, Fig.1:

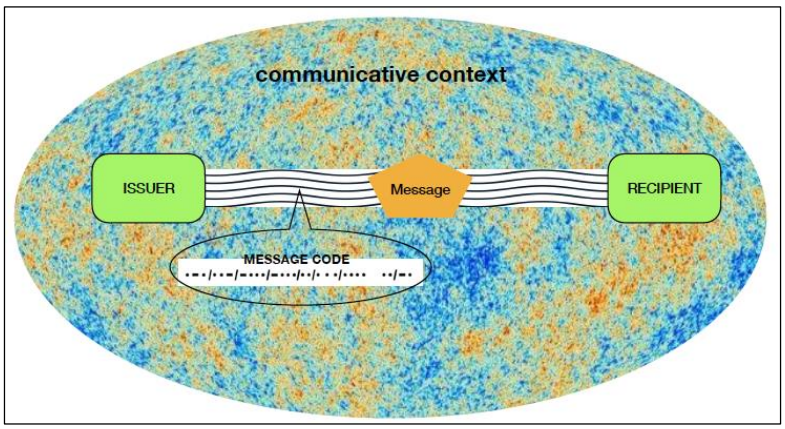

Figure 1 Scheme of communication process, from Author

The six fundamental factors of communication are:

- the issuer, that is, who produces the message;
- a code, which is the reference system under which the message is produced;
- a message, which is the information transmitted and produced according to the rules of the code;
- a context, in which the message is inserted and to which it refers;
- a channel, that is, a means by which the message can be transmitted;
- a receiver (or recipient) receiving and interpreting the message.

Schematically the cognitive process can be represented as

Interaction between elements -- modification of their state -- acquisition of the product effect

1.1. The result of such acquisition is defined Knowledge.

It is also important that during the communication the sender and receiver share the same code, because only in this way can take place the process of decoding, that is, of understanding the message. Issuer and receiver can exchange roles and be mutually exclusive, particularly in complex communication systems Fig. 2:

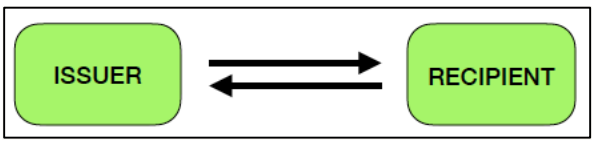

Figure 2 Reciprocity of roles in communicating entities

This is the generalized procedure by which matter interacts and decodes phenomena and events with which it comes into relation.

It is a faculty typical of complex molecular systems that can modify their steric conformation or structure and energy content in response to an effective stimulus [4].

If we think about it, it is the same process that the physicists who study the atom adopt to produce a useful result for the "knowledge of the structure of matter": they interact, under controlled conditions, elementary particles to record the changes produced because of the impact, and to obtain information on the structure of matter.

Consequently, the interaction is the first fundamental event of the cognitive process which must be followed by a second phase which consists in preserving the acquired steric/energetic modification so that it can be compared with others.

Interaction between molecular complexes occurs by direct or indirect contact and does not consider the nature of the interacting elements [5-7].

In direct contact there is a partial or total adhesion of parts of the interacting molecular complexes so that they can experience all the possible steric modifications and acquire the most advantageous ones for both.

Indirect contact takes place through the transmission and reception of coded messages that are recognizable by all physically separated parties. The transmission produces a sensitive modification of their conformational state, and of the environmental context where the transmission takes place, which is also an integral part of the cognitive process Fig.1.

The physical nature of interactive signals is different, that is, it is elastic mechanical, as for sounds, or electromagnetic, as for light, while the fundamental cognitive process is the same, whether it occurs between single molecules or macromolecules, both between complex biological systems.

In living organisms interactive structures are very numerous and present in the form of different receptor systems, so that the living, in their essence we can consider them complex transceiver systems able to acquire the adaptive characteristics to their environment and transmit them to the offspring.

Moreover, knowledge is transmitted both individually and collectively.

In summary, the necessary and sufficient condition for the occurrence of communication and knowledge is the presence of a material body in space/time that modifies its **informational state**, and simultaneously produces a **gravitational field** (according to Einstein's theory) able to attract or interact with other material bodies.

According to the different philosophical schools knowledge consists in an interchange between two subjects of which one, the acquaintance, has an active role, the other, the objective reality and the phenomena observed by the acquaintance, have a passive role. As we said before, this distinction makes little sense because the two subjects can reverse roles, and in reality, they are both active and passive in interaction.

If the modification produced by the stimulus can be recorded and preserved, then it becomes knowledge, that is, a collection of experiences useful for re-knowing similar future events.

From the premise, knowledge consists in being able to re-know experiences already lived, the set of which forms the complex of knowledge of the observer.

The ability to know is an intrinsic characteristic of living beings, which with evolution have acquired increasingly complex and effective receptor systems capable of receiving and re-knowing all the environmental stimuli to which they must be able to adapt.

For the description of the multiple stimuli and receptor systems present in nature and the process of sensory perception, I refer to my article [8].

At the basis of knowledge there is the elementary mechanism of the stimulus- response, the objective of this work is to investigate how human knowledge has been produced and how this knowledge allows humans and animals to interact with each other, both as individuals and collectively when forming groups.

What determines behavior between individuals and in a collective? And what dynamics intervene to regulate mutual relations when individuals form a group?

What mysterious collective communicative mechanism comes into play when the group behaves like a single individual?

The fact that the behavior of collective groupings takes place instantaneously and in unison and without any apparent need to coordinate individual intentions and wills beforehand raises interesting questions.

Which communication system is so fast and effective that it can be transmitted from one individual to another to obtain an instant and synchronized behavior?

There must be a special communication system that does not require the passage of interim information through normal communication channels, but spreads and connects all the subjects of the group and intervenes whenever two or more subjects meet and even before they enter sensory contact with each other.

Communication between individuals has long been studied in all animal groups, from insects to birds, to fish, to mammals and finally to man.

The research has produced interesting results regarding the interactive behaviors that regulate the reciprocal position of the subjects when they form a gathering, flocks, banks, herds, colonies, etc. But the mode and nature of communication has not yet been deciphered, except in a few cases, such as in insects, which communicate with chemical messages based on pheromones.

Gnoseology is the branch of philosophy that studies the nature of knowledge, and it is the set of ways in which the subject who observes the phenomena comes to know objective reality.

The gnoseological-epistemological investigation establishes a temporal and spatial separation between objective phenomena and cognitive processes, which does not exist in nature.

All phenomena of objective reality are known synchronously to their occurrence and are transmitted physically seamlessly to the perceptive systems of the observer.

Even the supposed capacity of speculative and abstract thought that metaphysics attributes to man and conceives of him as detached from objective reality, is but the result of learning and previous knowledge and experience gained through contact with the real world, which form the cultural heritage of individual researchers.

Therefore, another necessary and sufficient condition for cognitive experience is the spatial and temporal continuity of the interaction between objective phenomena and knowledge systems, even if the elaboration of events is after their occurrence.

This mechanistic conception of knowledge implies that the necessary condition for being able to know is to possess a communication system capable of receiving and transmitting recognizable stimuli using suitable signaling tools.

This also implies that interaction must take place between two or more individuals, or between the individual and their environment.

Moreover, communication can take place between individuals who use the same system of mutually recognizable interaction as code.

Even the matter that occupies the space in which interactions take place, defined as the field or place of events by quantum physicists, must be suitable to convey stimuli, which travel as messages in code, and are carriers of information content. In this sense, the field and the media are an integral part of the communicative phenomenon and knowledge.

It follows that the ability to know is commensurate with the quantity and quality of the communicative stimuli and the receptive tools that come into play in a particular environment and have a fundamental role in interaction.

1.2. Evolution of knowledge

Having defined the minimum necessary condition for knowledge, we examine how this capacity has evolved in the millennial history of the living to accumulate the extraordinary scientific and technological knowledge of today, and what prospects await us for the future.

According to the definition of knowledge proposed at the beginning of this paper, this can only take place between complex macromolecular systems able to modify their conformation and preserve it, so that you can compare and recognize future events with those already known.

The whole of the memory of events already lived form the foundations on which knowledge and knowledge is built.

The phenomenon of knowledge that we have hypothesized, is based on a molecular morphogenetic mechanism that has specialized during evolution in the macromolecular complexes that originated the primordial receptor systems.

In the prokaryotes Archea, who were the first living with a membrane of separation between the internal and external environment, such molecular complexes capable of interacting with the external environment had to be already present, and they had to reside in the separation membrane, interface, and border between the two [9].

The phenomenon of communication, as a fundamental element of knowledge, has then spread widely in nature, from the simplest organisms, the prokaryotes (without the cell nucleus), to the most complex, including man.

It is extraordinary to observe how even the simplest organisms can communicate with each other and pass on the acquired knowledge. Thus, for example, bacteria transmit antibiotic resistance to the whole colony by means of effector molecules formed by portions of bacterial DNA, the plasmids, despite having no structure attributable to neuronal networks [10].

These behaviors are a demonstration that the phenomenon of communication is universally widespread, and it is the intrinsic property of matter that allows knowledge.

The recent discoveries show us that knowledge is the daughter of communication and communication needs a substrate to manifest and express itself.

About 650 million years ago the most elementary and ancestral living forms appeared, and the first manifestation of communication between macromolecular systems capable of modifying their spatial conformation in response to external stimuli took place.

In trying to understand how this happened, let's take proteins for example.

These polymeric structures can assume infinite conformations simply by modifying the sequence of the monomers that compose them (amino acids), so they pass from a primary structure, to a secondary one rigidly dependent on the first, a tertiary, and finally a quaternary [11-13], Fig.3.

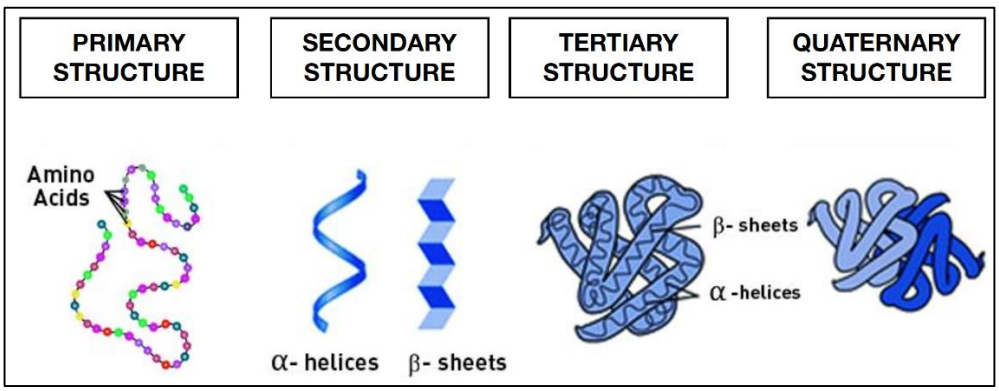

Figure 3 Schematic representation of protein structures- From toppr ,Biomolecule https://www.toppr.com/guides/chemistry/biomolecule/structure-of-proteins/

The conformation resulting from the progressive structural complexity of protein polymers, as well as depending on the primary structure, is strongly influenced by the chemical-physical environment in which they are immersed and are thus capable of adapting to the stimuli they receive from the outside. This again shows that the environment, or field, is also a necessary element of knowledge.

These are the properties, already highlighted above, that must possess a system of knowledge: ability to respond to stimuli variously encoded, adapt its conformation according to the stimuli received, and retain the conformational structure to "future memory".

It should be noted that the simple acquisition of any morphological conformation has a very great content and meaning of information, which is unique and unrepeatable.

In biology, early examples of replicative ability have been observed in some protein structures, such as prions that are capable of self-replication, or in amyloid structures discovered in the brain of Alzheimer's patients. These proteins are the pathological transformation of normal proteins, and can replicate, without the intervention of protein synthesis, they work as Primers for the mold of identical molecules.

In this case, however, the molecules produced do not have a physiological role, but rather pathological, they accumulate producing cellular damage. These anomalous structures are also an excellent example of how the wrong folding (misfolding) of protein structures, normally functioning, irremediably compromises their correct information and function [14].

Once acquired the ability to communicate the primordial macromolecules are segregated within membranes in ancestral cells, to follow their own autonomous evolution, and then acquire an initial specialization in their internal organelles.

1.3. Interaction between molecules at the origin of knowledge

How is the interaction in the cognitive phenomenon? This is the most important question that scientists and philosophers have been trying to answer for years.

All phenomena that occur in nature are produced by some type of interaction, capable of generating the reciprocal morphological and energetic variation between the interacting elements.

Whether it's subatomic particles, atoms or constellations of galaxies, every element that forms matter is in reciprocal contact with everyone else through modes that science has not yet been able to reveal.

Although the most advanced theories of modern physics on the formation and evolution of matter present plausible explanations, the phenomenon remains an intricate mystery.

However, some clues are emerging about how the elements that make up matter interact.

The nature of the interactions hypothesized is of electrostatic or electromagnetic type, and their study will allow to examine and understand the mechanisms of communication of molecular systems or of the above-molecular complexes, which include both the physiological and pathogenic cellular mechanisms or the behavior of collective groupings that form flocks, flocks, swarms, etc.

1.4. Electrostatic and electromagnetic interactions

According to quantum chemistry and mechanics these interactions include ion binding, covalent polar bonds, covalent nonpolar bonds, hydrogen bonds, and van der Waals, and depend on an imbalance in the distribution of the surface charges that cover the molecules and are responsible for the electric field of attraction or repulsion between molecules.

The nature of the interaction that takes place between the separated molecules that have a superficial charge finds its explanation in the fact that with the recomposition of the charges produces a condition of equilibrium and low entropy, typical of the living.

In nature there are other types of interaction that occur even at a great distance, and are not attributable to the separation of charges, but rather to the movement of charges within matter, are the interactions of an electromagnetic and gravitational nature.

Quantum physics describes this type of manifestation as the effect produced by electromagnetic waves that have the properties of mechanical waves and charged particles carried by them or depends on the modifications induced in space-time from the very presence of bodies.

Although they are widely spread in nature and represent the efficient cause of many natural events and the functioning of many electronic devices, their nature and understanding is difficult and enigmatic in many respects

1.5. Communication role of proteins

The processes that take place within cells are controlled by interactions between molecules, among which proteins play a fundamental role.

Proteins intervene in the processes of cellular regulation, enzymatic activity, initiation of DNA replication, translation transcription during protein synthesis, etc.

We have already described how this multiplicity of functions is due to the ability of these macromolecules to assume infinite structural conformations, in response to interaction with other molecules or environmental conditions.

In addition to proteins, other molecules have a fundamental role in the biological field.

According to the central dogma of biology formulated by Crick 1970 [15], priority in the functioning of living organisms would follow the order DNA- RNA- Proteins, according to which DNA would have a prominent role as promoter and regulator of biological events.

In subsequent developments, biological research has shown that there are other molecular mechanisms, epigenetic, that moving from the genotype (DNA) produce the effect on the phenotype and clarified the role that these regulatory molecules have as true responsible for the result.

In biological systems there are many molecules that can act in a coordinated way in the execution of the fundamental metabolic processes.

Coordinated and synchronous movement can occur because molecules that have the same structure respond in the same way when they are subjected to an identical electromagnetic stimulus.

So, all sodium ions, all potassium ions, all phosphates, or fatty acids with the same formula, will behave the same way, and follow the same metabolic fate when they are under the influence of an identical electromagnetic field. In eukaryotic organisms (with nucleus), the segregation of molecules within organelles greatly facilitates their coordinated functioning.

The presence in proteins of a conformation and charge typical of each one generates and receives unique signals of electromagnetic type that guide and orients them in the movements and metabolic paths in the great molecular chaos present in the living.

1.6. Difference between proteins and nucleic acids

1.6.1. Proteins are polymers composed of 21 different types of monomers, amino acids.

While the nucleic acids DNA and RNA are polymers composed of 6 different molecules that can be combined in various ways. The skeleton of DNA and RNA is formed in both cases by Phosphate, Sugar and 4 nitrogen bases, and is substantially the same, only changes the composition of sugars and the difference of a base, while the arrangement and succession of bases generates the genetic code, [16] Fig. 4.

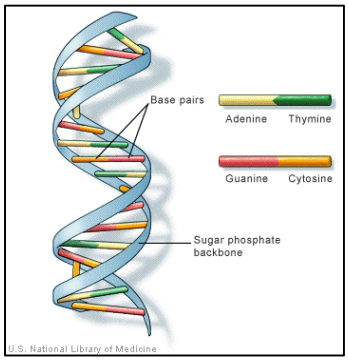

Figure 4 Structure of DNA- from Wikipedia

This results in a different ability to transmit the content of the information of the two groups of substances. In nucleic acids the information is entrusted to the sequence of the bases, an alphabet formed by only 4 letters, which are translated, during protein synthesis, into an infinity of protein structures. The limit of this communication system is defined by the fact that it can take place through the permutation of the 4 letters, the nitrogen bases, which produces 24 possible combinations, and the endless variety of information is entrusted to the length of the DNA [17].

- Proteins with 21 different amino acids can form an inexhaustible number of messages.
- A small protein, for example 50 amino acids, can take 2150 (twenty-one elevated to 50) possible combinations!!
- The information amplification system produced by protein synthesis is totally entrusted to proteins and allows the production of infinite protein forms and varieties of different phenotypes.
- For this reason, the fundamental component of living beings is entrusted to proteins, which perform structural and functional tasks

1.7. The phenomenon of perception in the transmission of knowledge

All manifestations that occur in nature are produced by some kind of interaction between material bodies, capable of generating mutual morphological and energetic variation.

The phenomenon of perception which we have discussed previously is widespread in nature at all levels of the organization of matter and is the physical basis of the cognitive process.

The cognitive process is the highest faculty that characterizes the human species and has allowed it the extraordinary evolution in the capacity of thought and abstraction accumulated in the culture of peoples.

The primacy of perception in the phenomenology of knowledge has been the subject of philosophy over the centuries.

Maurice Merleau-Ponty French philosopher (1908- 1961) has developed and speculated on the aspect of knowledge in his work "Phénoménologie de la perception", 1945 [18] in which it assigns the role of primary importance precisely to perception and analyzes the conditions and the gnoseological procedure necessary for the understanding of the phenomenon.

The approach of Merleau is both speculative-philosophical and physical-quantum type and assigns to the space-time dimension of knowledge the pivotal role together with the subject of knowledge.

The qualitative leap in the interpretation of the physical bases of the communicative phenomenon took place in 2013 by the quantum physicist Emilio del Giudice [19], who identifies in the collective behavior of the living a quantum event. In addition to this author, many other physicists have described biological processes in a quantum key, giving rise to quantum biology [20-22].

According to this conception, molecules and molecular and cellular aggregates interact with each other through electromagnetic interactions already described by quantum mechanics as a resonance phenomenon responsible for the mutual recognition of material substances.

The electromagnetic field phenomenon that occurs in the interactions between material elements, is the substrate of the forces that move the various states of aggregation of matter in a harmonious coordination towards objectives of orderly functioning or chaotic opposition and conflict.

In general, the cognitive process as epiphenomenon of communication has been observed by various researchers, linguists, philosophers, psychologists, biologists and so on, who theorized and described it in formal and behavioural terms, highlighting the procedures, codifying the implementing acts, assigning a substantial nomenclature to the individual operational aspects and context, the interpretative, semantic, connotative aspects, and so on.

While the nature of the physical mechanism underlying the phenomenon has not yet been given a comprehensive answer.

The purpose of this work is to identify or at least to hypothesize what are the mechanisms that allow individuals or a group of strangers to communicate and manifest collectively and in unison their emotional state and their spontaneous reactions.

1.8. Quantum interpretation of gregarious behavior

Gregarious behavior is the mechanism that comes into action when a very large group of people gather on occasions of strikes, protests, demonstrations of dissent, or rebellion, in response to unpopular decisions or policies of liberticide governments.

The same phenomenon can be observed in the Rave Party, where a group of people (usually young) who share the same social behavior, (spontaneity and absence of rules), crowd inside a musical event.

Or at sporting events, Football, Hockey, Baseball, etc. in which the crowd of spectators react in unison with a chorus of approval or disapproval, based on the result obtained by the team.

The common denominator of such manifestations is the very strong emotional component that is perceived, even observing the phenomenon as a spectator, emotion is probably the interpretative key to deciphering collective behaviors as expressions of subjective feelings that are confirmed and strengthened between people synergistically and synchronically.

At the basis of the historically relevant events is always the power of the emotions that push the masses to action, even if they often do not achieve the desired result.

For this reason, we consider it fundamental to investigate the elementary phenomena of knowledge in their physically relevant substrates of communication and sensory experience.

1.9. The force that moves the cognitive mechanism

In the communicative process it is important to make the distinction between semantically relevant explicit messages, words, gestures, body attitudes, and the emotional state that one wants or does not want to communicate. For example, when making false statements.

However, both find ways to be expressed and known.

The channels through which communication takes place are always wave-like, which have mechanical/elastic properties if they convey voice, acoustic, tactile messages, while they have the properties of electromagnetic waves when they transmit visual messages, thermal, gustatory, olfactory, and radio frequency messages.

The quantum and mechanistic interpretation of the communicative and cognitive process disregards any other consideration on the effects produced, on the meaning to be transmitted on the purposes of the process, but examines the mode of transmission, the channel used and the effectiveness of the system.

Then to return to the problem of knowledge because of communication, to understand the intimate mechanism of the process is to admit the existence of electromagnetic or other fluids that each material body simultaneously emits and receives from an analogous material body, and are able to re-know each other, if and only if, the two bodies enter into harmonic vibration.

1.10. Conclusion, The limits of knowledge

From all this, the question of the questions arises, and it is as follows:

Are we able to know any aspect of the universe around us? Is our cognitive structure suitable to grasp all aspects of the phenomena we observe in nature in their intimate essence?

The answer that comes naturally to give is NO, we are not able to fully know in the innermost details the real structure of matter that forms the universe and what is contained in it.

There is a more considered answer to the initial question, and it is that we **can** know the manifestations of the universe compatibly with the cognitive structures that we are equipped with here and now.

We are talking about the sensory and neuronal system that we have, which is not the only and the best possible.

At the lowest levels of our evolutionary scale, that of the anthropomorphic apes we find analogous manifestations of knowledge and self-awareness Fig. 5.

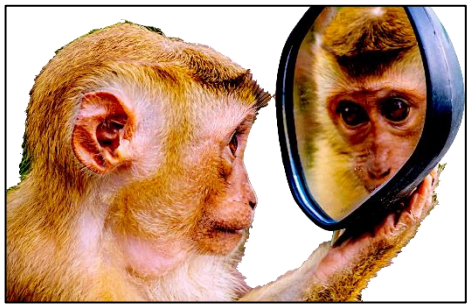

Figure 5 Knowledge and self-awareness in primates

Then to the question of what degree of knowledge we are able to obtain, the considered answer we can give is : we do not know.

Here lies the central point of all the questions that science attempts to answer.

The dichotomous nature of our neurosensory apparatus that on the one hand manages to create sublime works of thought, art and technology extremely evolved, from nanotechnology to aerospace and nuclear technology etc., but on the other hand it is not able to understand the intimate nature of matter or the universal evolution.

However, he manages to sublimate with his creative ability and imagination, what he is not able to perceive and interpret with his neurosensory apparatus.

So, in a nutshell,

- We have a cognitive apparatus that we do not know or know in little part;
- With this apparatus inadequate to know the infinite complexity of the universe, which moreover still appears to us in continuous becoming, we can only grasp the manifestations that we can record and interpret, by means of the theories we have formulated for our own use and consumption, but nothing more.

Even with the use of the advanced technological tools we have in order to carry out the most accurate investigations, the question of real-world knowledge still remains valid, because in the end those who must interpret the results of these observations are, once again our neurosensory apparatus. Therefore, let us not get out of this logical vicious circle.

The only possibility that remains is to rely on our limited resources gnoseology, and build a coherent and rationally acceptable theoretical system that these allow us.

Transcending this reality conditioned by our material essence is not possible, and I would say not even desirable.

In human experience, everything that can happen, when a subject explores natural and cognitive phenomena and meets on its path a similar, or a beautiful landscape, is to remain stunned and record the wonder and mystery that the encounter produces.

Compliance with ethical standards

Disclosure of conflict of interest

Authors have no conflict of interest in this work.

References

[1] A. Berea, Emergence of Communication in Socio-Biological Networks, Computational Social Sciences, https://doi.org/10.1007/978-3-319-64565-0_1

[2] Saussure, Ferdinand de. Course in General Linguistics. Eds. Charles Bally & Albert Sechehaye. Trans. Roy Harris. La Salle, Illinois: Open Court. 1983 ISBN 0-8126-9023-0

[3] N. S. Trubetzkoy ; Studies in General Linguistics and Language Structure, Anatoly Liberman June 2001

[4] Ryskina E.A. et al ; INTERMOLECULAR INTERACTION OF PROTEINS AND SMALL MOLECULES, European Journal of Natural History. – 2016. – № 3 – P. 8-13

[5] Gary D. Bader ET AL ; BIND: the Biomolecular Interaction Network Database, Nucleic Acids Research, 2003, Vol. 31, No. 1- Oxford University Press

[6] 1Ryskina E.A et al ; INTERMOLECULAR INTERACTION OF PROTEINS AND SMALL MOLECULES. EUROPEAN JOURNAL OF NATURAL HISTORY № 3, 2016

[7] G. LUDWIG HOFACKER et al; Intra- and Intermolecular Interactions W. Hoppe et al. (eds.), Biophysics © Springer-Verlag Berlin Heidelberg 1983

[8] B. Riccardi ; Specificity of cellular communication, from signal to functional response, World Journal of Advanced Research and Reviews, 2023, 18(03), 549–560

[9] Ander Camiruaga et al; Exploring the Influence of Intermolecular Interactions in Prebiotic Chemistry Using Laser Spectroscopy and Calculations, Chem. Eur. J. 2022, 28, e202103636 (1 of 7)

[10] Ying Huang et al ; The Roles of Microbial Cell-Cell Chemical Communication Systems in the Modulation of Antimicrobial Resistance , Antibiotics 2020, 9, 0779

[11] Yolanda Smith; Protein Structure and Function AZoNetwork Media Kit 2023

[12] Protein biochemistry; Encyclopaedia Britannica 2023

[13] Linus Pauling, Robert B. Corey, and H. R. Branson ; The structure of proteins: Two hydrogen-bonded helical configurations of the polypeptide chain, PNAS Vol.37 N 4 , April 1951

[14] Debanjan Kundu et al; Advances in protein misfolding, amyloidosis and its correlation with human diseases, Biotech (2020) 10:193

[15] F Crick, Central dogma of molecular biology. (PDF), in Nature, vol. 227, n. 5258, agosto 1970, pp. 561–3, Bibcode:1970Natur.227..561C, DOI:10.1038/227561a0, PMID 491391

[16] J. D. WATSON & F. H. C. CRICK ; Molecular Structure of Nucleic Acids: A Structure for Deoxyribose Nucleic Acid, *Nature* volume 171, pages737–738 (1953)

[17] Nucleic Acid , Encyclopaedia Britannica 2023

[18] Maurice Merleau Ponty ; Phénoménologie de la perception, Gallimard 1945

[19] Marco Bischof and Emilio Del Giudice ; Communication and the Emergence of Collective Behavior in Living Organisms: A Quantum Approach, Molecular Biology International Volume 2013, Article ID 987549, 19

[20] Jianshu Cao et al ; Quantum biology revisited , Sci. Adv. 2020; 6 : eaaz4888 3 April 2020

[21] Adriana Marais et al; The future of quantum biology , J. R. Soc. Interface 2018 15: 20180640.

[22] Johnjoe McFadden1 and Jim Al-Khalili2 ; The origins of quantum biology , Proc. R. Soc. A 474: 20180674.