CREATIVITY AND KNOWHOW IN TECHNOLOGY
An Application of Faggin Theory on Consciousness

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Introduction

Creativity is an important process in technology, being the source of innovative ideas that may be transformed into new technologies (Bonomi 2020). Knowhow is a knowledge indispensable to operate efficiently a technology, and both are present in the consciousness of a researcher or of an operator of a technology. Actually, creativity of an innovation is considered as an individual process (Dumbleton 1986), or as emerging from generative relations of various actors, for example among researchers discussing a new R&D project proposal (Lane, Maxfield 1995), while knowhow is little studied, and a description of its formation is given by using a model of technology developed in technology dynamics (Bonomi 2020). However, these studies on creativity and knowhow are not able to explain what really occurs in the consciousness of a researcher in the generation of an innovative idea, or of an operator using the knowledge of knowhow to operate a technology. An explanation about the process of creativity and knowhow in the consciousness of a researcher or an operator, may be given using the theory on consciousness of Federico Faggin, an Italian physicist inventor of the microprocessor working at INTEL, and after making studies on difference between human and artificial intelligence (Faggin 2024a). Furthermore, this theory may explain in detail how a new idea of a researcher can be communicated to another researcher, or how a knowhow of an expert can be transferred to a newcomer. This theory is based on existence of a reality independent by space and time, deducible by experiments and concepts of quantum physics, and affirms the existence of consciousness in a reality independent of space and time, transforming the brain signals, coming from our spatiotemporal reality, into the perception of a personal experience. In this working document we will discuss the existence of a reality independent of space and time deduced from quantum physics experiments, reflections about the reality of the nature, the various aspects of Faggin theory about consciousness with the redefinition of concepts of probability, information and knowledge, what it is known about the creative process of important technology innovations, the creative process in R&D activities, the nature of knowhow and the transfer of technology. Finally, it is discussed how the existence of quantum information might influence creativity for new technologies, and improvements of knowhow in operating a technology.

The existence of a reality independent of space and time

Quantum physics has shown that many of its experimental results are in contrast with our spatiotemporal view of the reality, violating in certain cases our rationality and logics, and many scientists have proposed various theories trying to explain these contrasting experimental results of quantum physics (Albert 1992). However, such theories do not have had any experimental demonstration, and sometimes they are even unable to imagine an experiment to prove or not their validity. We may give a description of these results, concerning the existence of a reality independent of space and time, using a simplified view of quantum physics, based on the Bohr concept of complementarity, without considering a more advanced view of quantum particles seen as an excited state of its quantum field. We discuss for this purpose the Heisenberg principle of uncertainty, the double nature of quantum entities following the principle of complementarity of Niels Bohr, the phenomenon of superimposition and that of entanglement.

The Heisenberg principle of uncertainty
The Heisenberg principle establishes that it is impossible to measure with an arbitrary precision, position and speed of a particle (in fact its momentum or mass x velocity) at the same instant in time. These limits may be extended also to the measure of time and energy of a particle. That raises the question about what is the reality existing under the values of space and time limited by this principle, and whether there is or not a space and time, practically not physically measurable in these conditions. Of course, that is not a demonstration of existence of a reality independent by space and time, but it does not exclude its possible existence.

The double nature of quantum entities
In quantum physics it is known the existence of entities that may have two different incompatible natures following the complementary principle of Bohr. For example, an electron may be considered a particle having a measurable mass and electric charge, but also existing as an electromagnetic wave. That has been demonstrated by sending a series of single electrons toward two holes put at a certain distance, and observing not the formation of two bands on the screen receiving the electrons corresponding to the crossing of the two holes, but the formation of many bands corresponding to a phenomenon of interference, typical of a wave going through two holes. That is incompatible with the view of an electron as a particle accompanied by its wave, as in this case the particle should go through the two holes at the same time. Metaphorically it seems that in this case the electron as particle does not detect the space between the two holes in a reality in which space does not exists. In fact, it appears that the nature of an electron as particle or wave depends on the type of experiment that is used to identify its nature.

The phenomenon of superimposition
In quantum physics the behavior of a particle may be described mathematically by a wave function that shows the possibility for the particle to have at the same time, two opposite values of one of its quantum properties in a phenomenon called superimposition. Metaphorically the particle may be considered analogous to a traffic light, that may be red or green but not at the same time, but presenting the two colours simultaneously in the case of absence of time in its reality. Making the measurement of this property, there is the collapse of the wave function and the appearance of one of its two values following a probability determined by quantum physics laws. That, with the previous description of the two natures of the electron, might be considered an indication of the paradoxical behaviour of a reality independent of space and time seen from a spatiotemporal point of view. The phenomenon of superimposition was the object of discussion between Albert Einstein and Niels Bohr. Einstein believed that in fact the superimposition does not exist, and the value of the measured property is a function of an unknown hidden variable determining the measured value, while Bohr sustained its existence. In order to show the validity or not of his idea Einstein proposed an experiment of contemporary emission of two particles that, for the quantum physics laws shall have two opposite values of one of its properties. Einstein sustained that each particle assumes the opposite values at the moment of its emission. Bohr sustained the fact that the two values were in superimposition for both the particles, and only the measurement of the property of one particle will show one of its two values, obligating of course the other particle to assume in a measurement the opposite value. Such experiment was realized after the death of Einstein and Bohr, and the observed measurements, treated with a suitable statistical method developed by John Bell able to discriminate the two possibilities, and it was demonstrated that the Bohr vision was right and then the existence of superimposition.

The phenomenon of entanglement
The existence of superimposition and of a reality independent of space and time was shown experimentally also in a quantum phenomenon called entanglement. In this experiment, as that used to demonstrate the existence of superimposition, there is the contemporary emission of two particles

having, by superimposition, both the two opposite values of a quantum property. Making a first measure on one particle it appears a value following a certain probability, and quantum physics establishes that the other particle shall assume the opposite values by a measurement. The question is how the second particle may know the result of the measurement of the first particle, that occurs with a certain probability, in order to respect the quantum physics laws. In fact, making a measurement on the second particle rapidly after the first measure, but at long distance between the two, a hypothetic signal informing the other particle should be transmitted at a velocity higher than that of light that is considered impossible in a spatiotemporal universe. The conclusion is that the appearance of the second value might occur instantaneously after the first measure, and the entanglement phenomenon might occur then in a reality independent of time and space.

The nature of a reality independent of space and time

The existence of a reality independent by space and time, as previously exposed, poses a question about the existing relations that it has with the spatiotemporal reality. Results of experiments of quantum physics may be interpreted considering a spatiotemporal reality, but some seem explained only considering a reality independent of space and time, such as the case for example of superimposition and entanglement discussed previously. Such situation has raised many considerations by scientists that has developed quantum physics. For example, Niels Bohr affirmed that we do not describe the nature as it is, but the way the nature appears to our study. Werner Heisenberg affirmed that what we observe is not the real nature, but the nature resulting from our method of investigation. All that raises the question whether the very reality of the nature is spatiotemporal or independent of space and time. We may observe that, when science became able to study the microscopic world of atoms and subatomic particles, inaccessible to our senses, it was necessary to develop quantum physics to explain the observed phenomena, with results incompatible with our common experience. On the other side, studying the world of galaxies, far from our perceptions of distances, it was necessary to adopt the general theory of relativity of Albert Einstein destroying our concepts of absolute space and time. We might conclude that our rationality based on a spatiotemporal reality, used by scientist but also by philosophers, would be actually a result of our biological evolution in order to assure our survival in the macroscopic world we live. Consequently, we would not observe the real nature but that resulting by our spatiotemporal method of investigation originated by our biological evolution.

The Faggin theory of consciousness

We present here a simplified interpretation of this theory (Faggin 2024a) that in certain aspects is coherent with a physical view of technology considered in studies on technology dynamics (Bonomi 2020) and technology innovation (Bonomi 2023). This theory is related with many aspects of quantum physics, and we limit here the description of concepts that are of interest in explaining creativity and knowhow in technologies. Actually, this theory includes many other arguments concerning for example the process of formation of life considering that the high number of molecules and complexity of processes existing in cellular entities are too specific to be simply the result of a Darwinian selection as observed in the development of living organisms, and also discussing the big bang generating the universe that in fact it does not have until now a physical explanation of its formation.

This theory may be explained starting from the consideration on how the signals in the brain, based on chemical and electrochemical processes occurring in the neurons network, are transformed into perceptions of personal experiences in our consciousness. That concerns for example colors, emotions and also knowledge. A personal experience that we cannot verify existing in exactly the same way in other persons, and corresponding to a philosophic concept called qualia. The same question concerns consciousness and the possibility or not to be the simple result of the complexity of the physical signals of the brain for humans, or the result of a sufficiently high complexity of software and hardware of a machine with artificial intelligence (AI). In fact, it is diffused the idea that the appearance of qualia and consciousness is simply an epiphenomenon, then a phenomenon consequent to the physical phenomena occurring in the brain or in an AI machine. Faggin theory refuses this possibility considering that in fact this epiphenomenon could not be explained by any physical process occurring in a spatiotemporal reality being in fact only a philosophic concept. On the contrary, his theory proposes that qualia, including knowledge, appear instantaneously in the consciousness from the diffusion of signal in the brain, as in the analogous case of entanglement in which the second particle assumes immediately the opposite value for the measure, that in a reality independent of space and time. In fact, consciousness is neither localized in the brain, nor in the various parts of the brain in which the physical signals are shown active. In this way it is possible to explain the human experience of qualia, such as for example the perception in the consciousness of the green colour, in fact originally an electromagnetic wave with a specific frequency, detected by the retina of a human eye, transformed in signals diffusing in the neurons network of the brain, and perceived by consciousness as the personal experience of the green colour. Another consequence of this view is the physical inexistence of AI, being only a set of physical processes, in particularly reproducing physically the logic states of 0 and 1 used in the development of algorithms allowing the functioning of an AI machine. In fact, the real intelligence is that of people that have developed the algorithms and designed the hardware of the machine (Faggin 2024a). The theory redefines in this way also certain common concepts such as probability, information and knowledge.

Probability

The theory distinguishes two types of probability. The first one concerns the classic probability, such as that of the result of launching a coin and the probability to obtain heads or tails. Actually, we know the mechanics that is at the origin of obtention of heads or tails, although we see the movements of the coin during the launch, we are not in measure to define them in detail in order to forecast the result. The second one is the quantum probability considering for example the probability that a particle assumes one of the superimposed values following a measure. In this case we cannot see how the particle assume the measured value, and we know that it does not exist any process forming one or the other results depending on hidden variables that were demonstrated experimentally inexistent. In fact, it seems there is a kind of free will of the particle to assume one or the other value determining the results. The consequence is that a full deterministic description of the nature in terms of space and time, as done in classic physics, is not possible being fundamentally dependent on the free will of particles composing the system under study, that are really determining the evolution of this system. Consequently, this free will influences also knowledge and then creativity and knowhow in the consciousness.

Information

The theory distinguishes three types of information. The first one is classic information, a spatiotemporal process consisting in air vibration, electric signals, electromagnetic wave signals, etc. that constitute the typical information formed, diffused and stored physically. This information reaches the human sensorial means, followed by a diffusion of signals in the brain. The second type is quantum information and, differently of classic information, presents quantum properties. That is the case for example of qbit used in quantum computers, based on the contemporaneous existence by superimposition of two opposite physical states of a quantum entity. That corresponds to existence of the logic states of 0 and 1 used in the development of algorithms for quantum computers. It shall be noted that quantum information, differently from classic information, cannot be known and cloned without destroying it. In fact, from a qbit, despite of superimposition of the two states, it is possible to obtain by measurement only one bit corresponding to one of the states and losing the other state (D'Ariano 2024). The Faggin theory considers that the conscious experience, for example of knowledge, is another aspect of quantum information (Faggin 2024b).

Then knowledge cannot be known in its entirety and cloned externally in form of classic information. Finally, the theory considers also a third type of living information of molecular nature, existing in living organisms, and assuring the information for biological molecular processes necessary to assure the living conditions (Faggin 2024a).

Knowledge

Knowledge, as qualia, represents what it appears in the consciousness following the brain signals stimulated by the sensorial means that receive information under one of the possible physical forms. However, the formation of knowledge is possible only if the signals of the brain may be interpreted, and not appearing casual, although these signals in certain cases seem to contain a knowledge but not interpretable actually by the consciousness. There is also the inverse process in which knowledge in the consciousness is transformed, through the sensorial means, into information of some physical nature, reaching the sensorial means of another person, and transformed into knowledge in his consciousness. However, it shall be noted that, because of the quantum information aspect of knowledge in the consciousness as noted previously, the acquired knowledge may be considered similar but not a clone of the original knowledge. Concluding, knowledge exists only in the consciousness, and information exists only as a physical process outside the consciousness, and may be physically transmitted or stored but not as a clone of the original knowledge (Faggin 2024b).

Creativity in technology innovation

In technology creativity is a necessary key process for the generation of innovative ideas that can be transformed into new technologies. This generation may be individual, as in the case of an inventor, or resulting by an individual but in the frame of generative relations formed by discussions among various actors, for example among researchers finding an idea for a R&D project proposal. The creativity aspects in the generation of innovative idea may be observed in detail considering what it is known in the generation of some important radical innovations. In fact, it is shown that in many cases the creative process is not necessarily only the result of combination of scientific and technical knowledge. In technology dynamics (Bonomi 2020) we have described in detail two cases. The first concerning the invention of the coffeemaker Moka Express by Alfonso Bialetti obtained observing a pot used in washing laundries (Bialetti 1995). The second case is the invention of Steve Wozniak of PC made possible combining a knowledge of the microprocessor and his task at HP to connect monitors with a centralized minicomputer. He developed in this way an electronic circuit connecting a key board with a domestic TV apparatus, and exploiting the computation capacities of the microprocessor (Isaacson 2010). Furthermore, we may cite also a third case concerning the invention of Samuel Morse of his alphabet born by casual tapping of the inventor on the railing of a boat during a trip. We may conclude that the creative process of an innovative idea for a new technology, occurring in the consciousness of the inventor, is based on a combination of elements of knowledge, not necessarily only of scientific and technical origin, that in accord with Faggin theory in which consciousness may host many other casual or diversified elements of knowledge useful in the creative process of innovative ideas. That poses a limit to the potential creativity of AI that considers essentially only scientific and technical elements, unable to take in consideration neither the enormous number of possible casual and diversified elements, existing in the human consciousness, nor to have the support of generative relations among various actors as in the case of humans. These conditions of AI might limit its inventive possibilities to incremental innovations but not for radical innovations.

Creativity in the R&D process

Following the model of R&D proposed in technology dynamics (Bonomi 2020), this activity may be considered formed by two cyclic fluxes of knowledge and capitals. Knowledge is generated by R&D activity that, combined with external knowledge, makes possible the generation of innovative ideas for R&D projects proposals submitted to selection for financing. The flux of capital is composed by the investments made for the R&D activity, the financing of entering in use of new technologies that produces returns of investments and new capitals for R&D following the various industrial strategies. In this way the available investing capitals finance selected R&D projects proposals for the R&D activity, and close in this way the two cycles of fluxes of knowledge and capitals. The creativity process occurs, either as individual creativity, or through generative relations, in the phase of formation of innovative ideas from available knowledge but not exclusively. In fact, generative relations may supply ideas to improve the R&D projects proposals during discussions among researchers and financing representatives making acceptable the proposal. Finally, the creativity is present during the activity of the R&D projects supplying new useful ideas for the development of the project.

Actually, in the mathematical description of the R&D model (Bonomi 2020), are introduced some simplifications concerning the role of knowledge in R&D. In fact, the elements of knowledge, exchanged among researchers in form of information packages, are attributed to the projects, and not to the researchers involved in the projects. In the same terms an innovative idea is considered generated by combination of packages of information although in the reality are a combination of elements of knowledge occurring in the consciousness of the researchers. These simplifications are necessary to put in a direct relation the number of projects and the formation of new technologies in a mathematical description of the model able to calculate the number of formed new technologies from a certain number of R&D projects. Furthermore, the combination generating innovative ideas in the model concerns only scientific or technical elements of knowledge, neglecting other types of knowledge, although they being effective for important technology innovations as described previously. This simplification is acceptable because these innovations have a scarce influence in term of number of generated technologies.

In conclusion the description of the creative process in technology innovation shows the importance of this process in various phases of the R&D activity, confirming factors suggested in R&D management favouring creativity such as: a suitable environment with trust, free flux of knowledge, possible autonomous decisions by researchers (Dumbleton 1986), and also attention to the promotion of generative relations (Lane, Maxfield 1995). Concerning generative relations, in fact they are not exploited in the financing system of R&D projects based on direct selection of projects proposals in absence of discussions with researchers that have prepared the proposals. In this type of financing R&D projects it is then lost the possibility to improve the proposals and to make more efficient R&D projects.

The nature of knowhow

The knowhow may be defined as a knowledge existing in the consciousness of a person, and obtained directly by operating a technology. This knowledge was present since the times of homo erectus that has started the working of stones to make tools, and transferring this technology in absence of writing and with possibly only primitive forms of language. The studies made on technology of about six hundred thousand years ago, well before the appearance of homo sapience, have shown a complexity in the formed tools considered derivable by a cumulative experience, then by a knowhow, and showing an important difference in respect to tools made by primates, or even by early homo species (Paige, Perrault 2024). This fact shows the existence of an activity of cumulation of knowhow and technology innovation in homo species, absent in the case of animals, and becoming a critical aspect of human technology evolution. This direct forming of knowledge from operating a technology, called knowhow, still persists in operating the modern technologies. Following the model of technology (Bonomi 2020), a technology is operated in optimal conditions of efficiency following its technological landscape. These optimal conditions are influenced by externalities, mainly with limited effects, and the operator changes the operative conditions in order to reinstate the optimal conditions using his knowhow. These influences of externalities are numerous and the corresponding interventions, necessary to restore the efficiency, are memorized and made available during the use of a technology. The knowhow is cumulated for example during learning by doing by a direct acquisition in the consciousness, and transferred from an expert to a newcomer, that by imitation and direct experience in using the technology. Sometimes the effects of externalities are important and the restoring of efficiency may need a change in the technological operations making a technological innovation normally of incremental nature. Following the Faggin theory of consciousness, knowhow is a knowledge existing in the consciousness of the operator, and may be influenced by other existing elements of knowledge useful to suggest the restoring way of the efficiency, or even suggesting modifications of the technology. On the other side, knowledge, as noted previously, having a quantum information aspect, it cannot be cloned for a transfer of knowhow from an expert to a newcomer. By consequence a transfer of knowhow from an expert to a newcomer in a simple oral or written form is insufficient and needs also imitation and direct experience by the newcomer, that forms in this way his knowhow. Furthermore, this knowhow cannot be exactly the same of that of the expert, and it will after follow its own path of cumulation.

The role of quantum information in technology

As described previously, either the process of creativity or the knowledge constituting the knowhow are present in the consciousness of a researcher or of an operator of a technology. Following the redefinition of the concept of knowledge, this one is existing in the consciousness, has an aspect of quantum information, and it cannot be cloned by transforming it in classic information that may be transmitted or stored in the spatiotemporal reality. That means that the derived classic information does not represent completely the knowledge in the consciousness, either concerning scientific and technological elements or knowhow. Consequently, there is a difference between classic information of scientific or technical nature transmitted to a researcher that will interpret the classic available information, transforming it into knowledge in his consciousness. An analogous difference is formed in the transfer of knowhow from an expert to a newcomer, taking account that in this case the possible classic information poorly corresponds to the knowhow of the expert, and the newcomer shall improve it by imitation and direct experience. It shall be noted that these two differences might be important in the process of innovation because of its combinatorial nature. In the case of scientific and technical knowledge, because of the diversity from the original knowledge, it may contribute to the generation of innovative ideas in the researchers receiving the incomplete information. In the case of knowhow, the difference between the knowledge of the expert and that of a newcomer makes possible improvements or incremental changes of the technology made by the newcomer. Consequently, this difference of quantum information origin may have a role in technology innovation and evolution.

Conclusion

The interpretation of the Faggin theory of consciousness allows a new view on creativity for technological innovations and on the nature of knowhow. Creativity in technology innovation results by combining possibly, not only elements of knowledge of scientific and technical nature, but also other casual and differentiated elements of knowledge existing in the consciousness, and able to generate important radical innovations influencing the technology evolution. Considering knowhow, it represents, in the interpretation of Faggin theory, a knowledge directly assumed in the consciousness through brain signals formed in operating a technology. The quantum information aspects of knowledge, hinders the possibility to clone it, that generating a difference of knowledge between that of the communicator and that of the receiver of knowledge, and this difference may contribute to make technology innovations or improvements of the knowhow.

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