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Schlüsselworte: Komplementarität, Prinzip des Wissens, Innovationsprozess, Innovationsskultur.

In this article the historical experience (20th c. – early 21st c.) of the application of physical concept of the so-called N. Borh’s principle of complementarity as a multipurpose approach to the interpretation of the most complicated phenomena of the real world is analyzed. It is the versatility and “productivity” of the application of this method that give reasons to claim that this principle of complementarity can be considered as a phenomenon of innovative (i.e. contrary to the traditional) culture.

Complementarity as a scientific principle was first formulated in 1928 by Niels Bohr, Danish physicist, laureate of the Nobel Prize, as he was trying to explain the “strange” at the time properties of the micro world. This principle proliferated to be part of various fields of physical science, natural science and other essential sciences. At the turn of the 21st century, the principle of complementarity was profoundly reviewed both as factor and phenomenon of global innovative processes, which are the main feature of modern evolutionary culture and science.

What is the essence of the principle of complementarity and its literally inexhaustible potential?

To answer this question, three contextually major and relatively fresh terms in their general structural sequence are to be outlined. They are “innovation”, “innovative process”, and “innovative phenomenon”.

The essence of these terms and their systemic defining as establishment of modern science and innovative culture of a certain scale can be traced by referring to the history of the emergence of the physical principle of complementarity and the way it gradually evolved, at first, into the universal principle of natural science, and later, into the general approach in epistemology, philosophy, science, and in the formation of holistic image of the real outer world (nature and society) in general, based on the unity of natural and humanitarian branches (forms, types) of science and culture.

Let us give this history a closer look.

Initially, it should be noted that the turn of the 20th century witnessed the situation named “the crisis of physics”. The matter was that the results of the majority of experimental researches clearly contradicted the essentials of classical science that were common at the time. In particular, it concerned the issue of atomic structure: E. Rutherford’s researches showed that every atom has “planetary” structure; inside the atom there is a massive positively charged nucleus surrounded by negatively charged moving particles called electrons. This movement of electrons is mechanical movement with centripetal acceleration conditioned by electromagnetic interaction of electrons with the atomic nucleus. In this part, electrons’ “behavior” totally complies with the laws of classical mechanics and electrodynamics. However, in accordance with some other laws of classical electrodynamics, an electron moving with acceleration should continuously radiate electromagnetic wave, thus losing its energy and “quickly” falling onto the atomic nucleus. It means that atoms will not be stable. Yet, the experience shows that atoms are very stable formations and they do not radiate energy under normal conditions. Moreover, if an atom creates electromagnetic radiation under certain conditions, this radiation is not continuous, but discrete. Minimum dose (quantum) of electromagnetic radiation (light) was fixed by Max Planck back in 1890. However, at the time, before the explanation of atomic structure, the concept of quantum had nothing to do with light. This did not change until 1913 and, in particular, until Niels Bohr’s work “Atomic and Molecular Structure”. In this work, in order to justify the contradiction between the research facts and existing physical theories, N. Bohr suggested two postulates, which were jointly defined as the “physical principle of complementarity”, as additional conditions. These additional conditions are known by every secondary school graduate as Bohr’s postulates that thoroughly explain the atomic structure of hydrogen. Let us recall the essence of these postulates:

- the electrons can only orbit stably, without radiating, in certain orbits at a certain discrete set of distances from the nucleus;
- the electrons can only gain and lose energy by jumping from one allowed orbit to another.

The essence of the existing “contradiction” should be specified here: the concept of the stationary orbits of an electron and its radiation is based on the classical concept of light quanta, whereas the calculation of these orbits was carried out in compliance with the laws of classical mechanics and classical electrodynamics. According to the famous physicist W. Bragg’s humorous statement, if one follows Bohr’s physical principle of complementarity, “God runs electromagnetics by wave theory on Monday, Wednesday, and Friday, and the Devil runs them by quantum theory on Tuesday, Thursday, and Saturday”¹.

Bohr’s physical principle of complementarity, together with other physical laws (and, first of all, in connection with Heisenberg’s uncertainty principle), became a crucial factor of the emergence and evolution of a new physical theory – quantum physics.

Application of the physical principle of complementarity rapidly embraced other fields of physical science. For instance, wave and corpuscular manifestations of light in the behavior of particles also proved to be complementary, which reflects actual dualism of the micro world. The list of similar examples of the application of the complementarity principle in physics can be continued. This innovative process in physics was accompanied by the appearance of different approaches to defining the principle of complementarity. Perhaps, the most common definition is as follows:

“In the field of quantum phenomena, most general physical properties of any system are expressed with the help of complementary pairs of independent variables (parameters, characteristics etc.), each of which can be better-defined only at the expense of the corresponding decrease in the degree of definition of the other”².

The prolificacy of this innovation (i.e. the concept of complementarity) also became evident in the process of solving many other natural and scientific problems. As a consequence, Bohr’s physical principle of complementarity was called a universal principle of natural science.

¹ K. Kyrylenko, *Teoretyczny i metodyczny osnovy formuwania innowatnoji kultury maibutnich kulturologiw u witzschomu nawtżalnomu zakladi* [Теоретичні і методичні основи формування інноваційної культури майбутніх культурологів у вищому навчальному закладі], Kiev 2015, p. 136 (http://nubip.edu.ua/sites/default/files/ui145/%D0%9A%D0%B8%D1%80%D0%B8%D0%BB%D0%B5%D0%BD%D0%BA%D0%BE_0.pdf, 1.06.2015).

² Ibidem, p. 137.

Having introduced the concept of complementarity concerning the explanation of atomic structure, N. Bohr immediately noticed it was the key to solving many other scientific problems, including those having nothing in common with physics and natural science. Thus, in one of his next scientific works (coming after the above-mentioned) he emphasizes the importance of the complementarity principle in psychological research and epistemology. In particular, he claims that “the physical aspect of the complementarity principle is only a particular case of a more general approach: trying to analyze our worries, we stop anticipating them. In this sense, we find out that there is complementarity between psychological experiments, which are normally described using such words as »thoughts« and »feelings«, just as it exists between data in the atomic behavior”³. Bohr also mentioned that “the human mind has certain features which are similar to the characteristics of quantum phenomena. Observation of feelings and the process of experiencing them are two complementary occasions [...]. Here we find the illustration of the old truth saying that our ability to analyze the harmony of the physical world and the breadth of its perception will always remain contradictory and complementary in their correlation”⁴.

N. Bohr’s genial predictions about universality of the complementarity principle came to be so prophetic that it would be unfair not to call its further spread within all the other disciplines an “innovative phenomenon”, since nowadays this principle is applied in almost all the methods and sciences that learn inanimate and animate nature, human, and society. And this is no coincidence, because the dualism of our conception of the real world through interconnection of space and time, synergetic ideas about ordering of condition of complicated systems on the one level and their chaos on the other level, complementarity and consistency of fundamental universal constants (the universal gravitational constant, the speed of light, the minimum electric charge etc.) is also reflected in human’s spiritual and moral perception of the world. Human’s nature is also dual as the world is approached from the outside, including the standpoint of God, and from the inside with the help of feelings complemented by devices. Hence, there is the dualistic description of nature, based on both humanitarian-spiritual viewpoint and objective-physical conceptions. One part of human existence is explained successfully with the help of science, while the other one requires art, religion or some other non-mechanistic but spiritual methods to describe the world.

Let us review several examples from the history of development of the world culture in the context of the complementarity principle.

³ Ibidem, p. 137.

⁴ Ibidem, p. 138.

N. Bohr himself believed that “every saying should be interpreted both as an affirmation and as a question”⁵. The world-famous physicist, P. Dirac noted that “according to Bohr, the highest wisdom should be necessarily expressed with the words the sense of which cannot be clearly defined. As a consequence, the truthfulness of the highest wisdom is not absolute but only relative; so, the opposite saying is legitimate and wise as well”⁶. A. Einstein said that “physical concepts are free creations of the human mind, and are not, however it may seem, uniquely determined by the external world”⁷. French mathematician J. Poincaré said that “no physical experience can confirm the truthfulness of some transformations and reject others as inadmissible”⁸. He also wrote that “learning the history of science, we notice two phenomena that can be named contradictory: sometimes it is simplicity which is hidden under what is apparently complex; sometimes, on the contrary, it is simplicity which is apparent, and which conceals extremely complex realities”⁹. L. Humilev noted that “when you are rich with social freedom, you lack contact with nature – here, the complementarity of geographical and physiological essences of human environment are also obvious”¹⁰.

An interesting interpretation of Bohr’s principle applied on the “household level” is found in the essay “Low truths” by a famous film director, A. Konchalovsky: “A person, who is free outside, has to be extremely organized inside. The more a person is organized, i.e. deprived of internal freedom, the freer society they create. Everybody knows limits of freedom that is allotted to them and doesn’t burden themselves with its limits. Self-restraint of each person is the basis of everybody’s freedom”¹¹.

The list of examples of successful application of the complementarity principle can be continued indefinitely. It includes synthesis and analysis, subject and method, vertical and horizontal, complexity and organization, rational and intuitive, the right hemisphere of the brain and the left one, cognition and aesthetic perception etc. For instance, one of the features characterizes the object, while the other one characterizes environment. Thus, as Bohr said, “we

⁵ К. Kyrylenko, *Dopownuwanist iak universalnyi princip sutzasnoi nauki i fenomen inowatzinoi kultury* [Доповнюваність як універсальний принцип сучасної науки і феномен інноваційної культури], *Gumanitarny Studii* [Гуманітарні Студії] 25 (2015), p. 68 (http://www.philosophy.univ.kiev.ua/uploads/editor/Files/Vydanna/Gumanitarni%20studii/%D0%93%D0%A1_25_5.pdf, 1.06.2015).

⁶ Ibidem, p. 68.

⁷ Ibidem.

⁸ Ibidem.

⁹ Ibidem.

¹⁰ К. Kyrylenko, *Teoretytzny i metodytzny...*, p. 139.

¹¹ Idem, *Dopownuwanist iak universalnyi princip...*, p. 68.

deal with different but equally significant aspects of a unified and clearly definite complex of information about the system”¹². N. Bohr emphasized the impossibility to describe a complicated phenomenon with the help of a single language and, a fortiori, in a single and thorough way.

Bohr’s principle of complementarity excluded the possibility to describe the world by dividing it into parts with full description of each part. No separate discipline can be self-sufficient; it requires to be complemented with other branches of science (natural sciences – humanitarian sciences).

Let us specify some other opportunities for effective application of Bohr’s complementarity principle. For example, it may be applied in such correlations as whole and part; structure and functions of a complex system; chaos and order in self-organization during the evolution process; stochasticity and determination; accident and regularity; “yang” and “yin” (according to eastern mysticism); anthropic principle and laws on physical and informational interactions; social and biological forms of movement; essence and its manifestation; man and woman etc.

According to the principle of complementarity, existent is only what we can measure and (or) evaluate. If there is no connection between facts, we cannot establish these facts. We can only know the things that are somehow connected with each other and with us.

One of the definitions of the complementarity principle, which is the closest to the humanitarian approach, also belongs to N. Bohr: “Truth and clarity are complementary”.

The academician B. Rauschenbach is often referred to as an example of the complementarity in the artist’s perception of the physical world. “When depicting a room, for instance, one believes that walls are the main element of a picture and portrays them in a clear manner, neglecting the floor. Another artist shows the floor the way he sees it, significantly distorting the look of walls. There are different ways to place accents. The choice of one or another variant is the matter of the artist’s perception and aim. That is why the words of an artist »this is the way I see it« have an objective physical meaning: the vertical (walls) is important to one, the horizontal (floor) is essential to another. They do not work together! If one wants to portray the floor right, he will »skive« depicting the walls. And another, to whom the walls are of greatest importance, will necessarily »lie« portraying the floor. What is crucial to each of them is what they convey better, »more correctly«, ignoring the rest”¹³. B. Rauschenbach noted: “Different artists perfectly convey different traits; as a result, we get

¹² Idem, *Teoretytzhny i metodytzhny...*, p. 140.

¹³ Idem, *Dopovnuvanyist yak universalnyi princip...*, p. 69.

different pictures, and all of them are equally »right«, and it is fair. Undoubtedly, such different pictures influence us differently, even though they depict the same object. Therefore, the real subject and its subjective perception complement each other creating some brand new »reality«¹⁴.

The universality of the complementarity principle is also proved by its reflection in the “status of equality”, mutual respect between participants of any discussion, when everybody does not only respect the viewpoint of each other, but is also ready to limit the area of their own opinion so that it fits into the acceptable framework established from without by other specialists. As for research and forecasting (including forecasting innovations), the principle of complementarity defines the methodology of cognition: the greater the simplicity and the area of research, along with the application of its results, the lower the accuracy and specificity of the estimate.

Finally, there is one more sphere of social and human vital activity, in which the realization of the complementarity principle has always been topical, especially nowadays, in the era of globalization. It is education, in particular natural-scientific education of humanitarians and humanitarian studios for “techie”. (The issues of globalization in the field of culture and education have already been addressed in the previous parts of the manual).

It is necessary to forewarn that the application of the complementarity principle should be regulative in order not to neglect the criterial factor of a discipline, in particular the imperative of scientific correctness (“not to multiply values”). This was emphasized by S. Krymskyi, a famous Ukrainian scientist-philosopher, an acknowledged expert in the area of interpreting various issues of non-classical epistemology and epistemology of science¹⁵. In his work “Science as a phenomenon of civilization”, S. Krymskyi stresses that there is no need to provide complementary essences, in case it is possible to explain the phenomena by means of one grounding¹⁶. The reason is that, in spite of the seeming presence and naturalness of the imperative of scientific correctness, it has a “serious and farsighted ideological meaning”¹⁷.

The above examples representing humanitarian and natural-scientific branches of science and culture show that there is a problem of searching the ways to consolidate their languages. This appears possible only from the viewpoint of theory of self-organization and the synergetic approach, because the nature is fundamentally unified with all its facets being conditional and only reproducing

¹⁴ Ibidem, p. 69.

¹⁵ S.B. Krymskyi, *Zaniti filozofskich smisliv [Zaniti filozofskiykh smisliv]*, Kiev 2003, p. 8–21.

¹⁶ Ibidem, p. 157.

¹⁷ Ibidem.

gradual approach of the humanity's collective mind to the cognition of the world. The unity of all beings and their various manifestations should also determine approximation and mutual penetration of natural-scientific and humanitarian approaches to the cognition of the world. Along with this, the role of the researcher is also changed: they themselves become an integral part of the image of the world they create, which consequently stops being only natural and scientific. That is why the role of the illogical component of the mind in cognition is becoming more significant, and the influence of intuitive and creative methods in cognition of truth is growing.

So, today the problem of consolidation of the two branches of modern culture is becoming more and more urgent, and the way V. Vernadskyi saw this unification, it is possible only if it is based on science.

The holistic approach to perception of the real world, taking into account the natural-scientific and humanitarian methods of its study and application of the complementarity principle as an instrument of cognition, will provide an opportunity to solve the problem of a fuller understanding of the real world. This application might even be able to change ideology, discover the reasons of shocks in modern society etc.

The reason why it is difficult to join humanitarian and natural-scientific cultures in the process of cognition of the real world is mostly the lack of a common language and conceptual apparatus, which will obviously be the theory of self-organization and the synergetic approach. However, according to the academician V. Hinzburg, humanitarian intellectuals receive one-side education and often demonstrate the medieval level of natural-scientific knowledge. A humanitarian, not possessing natural-scientific logic and not understanding the essence of the real (physical) world, aiming to explain public and social, psychological or economic processes, often use only external attributives of new notions, including such synergetic conceptions as bifurcation, the catastrophe theory, blow-up regime, nonlinear evolution etc. Undoubtedly, the opposite idea about "responsibility" of natural science and its method of scientific rationalism over all the negative consequences of scientific and technical progress also makes sense, and, respectively, its development should be placed under humanitarian control.

Thus, defining complementarity in the most general (phenomenological) context, it can be claimed that science is a backbone of mutual understanding, art (religion etc.) is a basis of perception of the world, and their sum is a base of harmonious ideology. Only the holistic view over the real world (nature and society) can provide successful solutions to problems of human life support, as well as demographic, ecological, and socio-cultural issues.

KOMPLEMENTARNOŚĆ JAKO ZASADA EPISTEMOLOGII

(STRESZCZENIE)

W artykule autorka poszukuje istoty zasady subsydiarności, a także próbuje ustalić możliwość jej zastosowania w różnych obszarach nauki i praktycznej działalności. Na podstawie przeprowadzonych analiz zauważa, że dzięki wykorzystaniu tej zasady na przełomie wieków XX i XXI zdynamiczowany został w nauce i kulturze proces ich innowacji.

COMPLEMENTARITY AS A PRINCIPLE OF EPISTEMOLOGY

(SUMMARY)

In this article the essence of the principle of subsidiarity and experience of its application in various fields of scientific and practical activity is examined. Use of this scientific principle of the XX–XXI centuries began as well-defined innovation process and ultimately as a phenomenon of innovation culture.

KOMPLEMENTARITÄT ALS PRINZIP DER ERKENNTNISTHEORIE

(ZUSAMMENFASSUNG)

In dem Artikel wird das Wesen des Grundsatzes der Subsidiarität und der Erfahrung ihrer Anwendung in verschiedenen Bereichen der wissenschaftlichen und praktischen Tätigkeiten besprochen. Die Nutzung dieses wissenschaftlichen Prinzips im 20. und 21. Jahrhundert wird als gut definierter Innovationsprozess und letztlich als ein Phänomen der Innovationskultur behandelt.