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Synergetic Approach to Teaching Natural Sciences in Medical Universities

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Abstract

Synergetic approach is a set of principles, ideas and methods used by synergetics, an interdisciplinary science and educational discipline studying integration trends and processes of self-organization and ordering in open, non-linear, dynamic, complex systems of different nature. The modern development of science and education has enriched synergetics with a new, deeper meaning. Synergetics is a science that describes the processes of the emergence of order from disorder (chaos) and vice versa, as well as integration processes associated with changes in the structural features of the studied systems through their internal connections and interactions with the environment.

Keywords: *Synergetic Approach; Feynman Classification; Nucleation; Carcinogenesis; Grid Cells; Hexagonal Structures*

Introduction

The field of science and education, for which Professor Hermann Haken from the Stuttgart University (Germany) proposed the name "synergetics", began to develop in its modern form about 50 years ago [1]. In fact, this term historically originated in the ancient civilizations of Greece and Rome in connection with the joint action of various medicines. The famous English physiologist Charles Scott Sherrington, winner of the Nobel Prize in Physiology or Medicine in 1932, used this word more than a hundred years ago.

Most of the modern achievements of synergetics are due to the possibility of integrating and transferring the results of one educational discipline or science (for example, physics, mathematics or informatics) to similar objects of another educational discipline or science (for example, medicine). At the same time, results obtained in physics, mathematics, and informatics are usually more accurate and quantitative, while due to the considerable complexity of medical problems, their description, without the use of such a synergetic analogy, is likely to be possible only at the qualitative level [2].

Basic principles of synergetics

The uniqueness of synergetics lies in the possibility of unification on its basis various phenomena of nature and society that previously belonged to the competence of various branches of scientific knowledge. The development of synergetics at the end of the twentieth century made it possible to create, together with philosophy, another new integrative approach which largely compensated for the processes of differentiation that have been so characteristic of the post-Newtonian sciences over the past four centuries.

Obviously, the unification of the different phenomena becomes possible not for all systems, but only for some of them. Such systems must satisfy the following important conditions [1,2]:

a) They are open, i.e. exchange information, matter and energy with the environment;

b) They are non-linear, i.e. there must be feedback between quantities that describe the state of these systems;

c) They are dynamic, i.e. various non-equilibrium processes take place in them, which change in time and space;

d) They are complex, i.e. they include a large number of interacting subsystems.

The methodological basis of the synergetic approach are modern methods used to study the self-organization and ordering processes in open systems of different nature (medical, physical, chemical, biological, educational, etc.). This approach is based on such well-tested and precise methods as the theory of phase transitions, the theory of non-linear oscillations and autowaves, kinetic models “brussellator”, “oregonator”, catastrophe theory, fractal theory and others [1,2].

Here is a far from complete list of sciences, educational disciplines and examples of processes for which a synergetic approach is effectively used [1,2]:

- Medicine - Reverberators (spiral waves) in the myocardium, hexagonal structures on the retina, synaptic transmission, carcinogenesis;
- Physiology - Hexagonal structures in the brain, being responsible for the spatial orientation of humans and animals as well as the risks of developing Alzheimer’s disease;
- Ecology - Fluctuating dynamics of population size, the emergence of epidemics (pandemics);
- Psychology - Hysteresis and bistability in the visual perception of objects;
- Computer technology - Biocomputers and parallel computing systems;
- Sociology and political science - The formation of public opinion; stability of political systems, etc.

The Feynman Classification of the Three Stages of the Study of Natural Sciences

To understand the uniqueness of the synergetic approach, the so-called “first principles” defining the basic laws of nature and society are of particular importance. In this regard, Richard Feynman, winner of the 1965 Nobel Prize in Physics, in his famous “The Feynman Lectures on Physics” [3] essentially proposed a classification of the 3 stages of cognition. It was suggested for the first time in [4] to name this classification as “The Feynman Classification of the Three Stages of the Study of Natural Sciences”. The milestones of this classification are as follows:

- 1st stage - accumulation of experimental data. As an example, Feynman cited light refraction experiments conducted by Claudius Ptolemy around 140 AD. It should be noted that there are enough sciences (educational disciplines) that are in the 1st stage, associated with the accumulation and systematization of experimental data.
- 2nd stage - creating a theory of the phenomenon under study. At this stage, Willibrord Snellius in 1621 discovered “the law of light reflection”, well known from the school course of physics which connects the angles of incidence and refraction of light with the relative refractive index of two media.
- 3rd stage - understanding the “first principles” that explain the reasons for the laws describing experimental data. Richard Feynman used the following words for this crucial stage [3]: “…the real glory of science is that we can find a way of thinking such that the law is evident”. For the light refraction, Pierre de Fermat discovered such a first principle in 1662, later named “The Fermat’s principle of least time” stating that the ray of light chooses a trajectory, the movement along which takes the minimum time.

Examples of synergetic approach at the boarder of medicine and natural sciences

As specific implementations of the synergetic approach to the use of natural sciences in medicine, let us briefly consider the following examples [5-9]: The first example concerns the use of ideas of the physical phenomenon of nucleation to create a hypothesis for preventing the process of carcinogenesis [7,8]. Synergetic isomorphism (similarity) of nucleation, a special case of which is the formation of nuclei of the liquid phase from metastable water vapor, and carcinogenesis gives a possibility to suggest the new hypothesis to prevent the growth of malignant tumors. This hypothesis involves the use of surface-inactive substances increasing the coefficient of surface tension. The study of the nucleation dynamical process demonstrates such specific features:

a) If the size R of the new phase nucleus is less than its critical size Rcr, then an energetically favorable process is to further reduce the size, i.e. such subcritical nuclei are spontaneously decreasing their sizes;

b) If the situation is opposite, i.e. R>Rcr, such supercritical nuclei are growing.

Since the critical size of the new phase nucleus is directly proportional to the surface tension coefficient, it was suggested to use non-toxic substances that increase the surface tension coefficient to prevent the formation of malignant tumors.

The second example of using the synergetic approach is directly related to the 2014 Nobel Prize in Physiology or Medicine. As is known, this prize was awarded to John O'Keefe, May-Britt Moser and Edward Moser "…for their discoveries of cells that constitute a positioning system in the brain" [5]. To explain the formation of the hexagonal structure of grid cells in the brain, Edward Moser and May-Britt Moser suggested using the analogy between the grid cells and vortex structures in superconductors discovered by Alexei Abrikosov, the 2003 Nobel laureate in Physics [6].

A new approach to explaining the appearance of hexagonal structures of grid cells in the brain was proposed in [4,9], being more attractive in the author's opinion, than the idea of the similarity between two systems of grid cells and Abrikosov's vortices with repulsive interactions in superconductors in magnetic field. The main idea of our approach is the synergetic similarity of the processes of formation of hexagonal structures near bifurcation (critical) points in various systems of animate and inanimate nature. This idea allows one to transfer the rigorous theoretical results obtained by H. Haken [1] for a relatively "simple" physical system of Benard cells near the state of hydrodynamic instability to a much more complex neurophysiological system of grid cells in the brains of humans and animals. The powerful methods of the fluctuation theory of phase transitions such as the scaling and conformal invariance hypotheses; the generalized Ginzburg-Landau kinetic equations for order parameters, the conception of the universality classes are applied that allow formulating [9] basic conditions of the similar behavior for systems of different nature (see detail in [4,9,10]). Thus, the first principle of hexagon emergence in the system of grid cells in the brain appears due to non-linear interaction of fluctuation of the order parameters in animate and inanimate nature.

Conclusion

The modern educational system is actually a synergetic system, i.e. it is open, non-linear, dynamic and complex. The importance of synergetics for education and science is associated with the possibility of creating interdisciplinary dialogue, more effective study of interdisciplinary links, using this new interdisciplinary direction for a deep understanding of the unity of laws of nature and society, and thus personal development as the ultimate goal of all educational activities.

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