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TEACHING THE SECTIONS OF A PHYSICS COURSE THROUGH DEVELOPMENT BASED ON THE PRINCIPLES OF CONTINUITY AND COHERENCE

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Abstract

This article describes the methodology of teaching the sections of a physics course—molecular physics and quantum statistics—through developmental instruction based on the principles of continuity and coherence. First of all, the principle of continuity ensures the integrity of interconnections between successive stages of growth when the levels of educational technology and content at various stages of education transition to a new qualitative level. Subsequently, based on the new theory achieved at a higher stage, it helps to analyze the shortcomings and advantages of the previous one, to evaluate scientific concepts more deeply, and to promote the development of the knowledge being acquired.

Keywords

principle of continuity, principle of coherence, didactics, quantum statistics, molecular physics, continuity of education, molecule, photon.

Today, one of the most important strategic directions of higher education is to achieve the implementation of the principle of continuity at all stages of lifelong education. The principle of continuity, which is a necessary condition for ensuring lifelong education, primarily guarantees the integrity of interconnections between successive stages of development as educational technologies and content at different levels of education move to a new qualitative stage. Secondly, the principle of continuity, based on the new theory attained at a higher level, helps to analyze the strengths and weaknesses of the previous one, to evaluate scientific concepts more deeply, and to further develop the knowledge being mastered.

Organizing students' learning processes on the basis of continuity is considered one of the pedagogical challenges. At the stages of lifelong education, principles such as scientific validity, sequence, systematization, and continuity—being among the main principles of developmental teaching—play an important

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role in the fundamental improvement of the physics education system. That is, in physics education, continuity serves to ensure that the stages of learning—from simple to complex, from primary essence to secondary, tertiary, and higher-level essences; from facts to concepts, ideas, doctrines, theories, and ultimately to a scientific worldview—are interconnected and integrated into a coherent whole.

It should be noted that with the increasing pace of development of science and technology, scientific theories, ideas, principles, concepts, and research methods are also rapidly developing, being continuously enriched by new scientific achievements. Therefore, today it has become a vital requirement of the time that a higher education graduate should not only possess thorough and comprehensive knowledge, but also be able to constantly develop their professional competencies and keep pace with modern developments. Within the framework of lifelong education, there are various approaches to implementing continuity, which is one of the main conditions for ensuring the continuous professional development of an individual.

Continuity, as a philosophical category, represents the connection between the elements of the complete stages of existence and cognition, and its essence lies in the preservation of the integrity of the whole as a system during the process of change of its parts. Continuity links the past with the future and ensures the stability of the whole. Thus, in modern philosophy, coherence has a unified interpretation: continuity means that in the process of development of material objects, certain elements of the previous state are preserved in the newly emerged state.

A clear example of the application of continuity in physics is the correspondence principle. Since this idea played an important role in the interpretation and development of quantum-mechanical formalism, it is appropriate to briefly outline the history of its emergence.

The main difficulty lay in understanding the relationship between quantum and classical physics. Planck's radiation law was based on the discreteness of energy and therefore contradicted classical physics. Its formulation required a departure from the framework of classical physics. At the same time, Planck's formula for the spectral density of radiation energy includes the Rayleigh–Jeans and Wien formulas as limiting cases. The Rayleigh–Jeans formula is based on classical principles, namely the law of equal distribution of energy in space. Thus, Planck's formula did not completely break away from classical physics; rather, within certain limits it corresponds to the existing laws of electrodynamics [1].

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The introduction of photons by Einstein restored the corpuscular theory of light. However, since the photon energy formula contains the concept of velocity, it could not be said that the wave theory was replaced entirely. Bohr's postulates were also based on Planck's ideas as refined by Einstein and practically substantiated through specific laws. Bohr's main goal was not merely to interpret or confirm these postulates, but to test their explanatory power [2]. On the basis of Bohr's theory, a correct explanation of the spectral regularities of the hydrogen atom was provided. Applying this idea to multi-electron atoms expanded its scope, while at the same time clarifying its relationship to classical physics. A major step in this direction was Bohr's work *"On the Quantum Theory of Radiation"* published in 1916. Bohr's postulates demonstrated that Planck's formula for the spectral density of radiation energy could be derived. It was here that Einstein first considered spontaneous and induced transitions and introduced the concept of probability coefficients. However, at that time probabilistic ideas did not yet play a decisive role in quantum theory. Einstein applied probability coefficients to transitions between stationary states. As a result, the idea emerged that, beyond mere limiting correspondence, there exists a deep similarity between new and old ideas.

The correspondence principle thus appeared to serve as a bridge between classical and quantum physics. From a philosophical point of view, the correspondence principle substantiates the development of physical theories not through their mutual negation, but through their reliance on one another. In this interpretation, the correspondence principle can be regarded as a natural-scientific confirmation of the dialectical materialist doctrine of relative and absolute truth.

In the history of the development of physical theories, the correspondence principle has significant heuristic value. At the same time, it performs a logical function by ensuring the connection between existing theories. Based on an analysis of philosophical literature, the following can be identified as the foundations of coherence in the educational process:

- the concept of coherence reflects the objectively existing development in nature, society, and thought, characterizing both the connections within development and the development of those connections themselves. Since didactics is the theory of teaching and learning, it must characterize the development of these processes. Therefore, coherence is related to didactics, that is, it is a didactic concept; at the same time, since coherence is a philosophical concept, it is connected with philosophical categories. For didactic research, it is important to analyze the interrelations within such concepts as "coherence and generalization," "continuity and interdisciplinary connections," and "continuity and systematization";

• since development has both quantitative and qualitative aspects, types of coherence should be considered in accordance with the level of development of cognition, based on the relationship between the concepts of continuity and generalization in knowledge. Thus, this approach can also be applied to didactic research;

• continuity also constitutes the methodological foundation of pedagogical and didactic research.

Analyzing continuity in education, B. G. Ananyev wrote the following: "One of the central pedagogical problems is the development of students' knowledge in the process of teaching the fundamentals of science. Continuity is one of the forms of such development; it implies the interconnection of acquired knowledge in consciousness, its systematization, and its application in various situations in education and life" [3].

A sufficient mastery of probabilistic and statistical ideas not only expands students' knowledge, but also makes an effective contribution to the formation and development of their scientific worldview. At the same time, it reveals continuity in their intellectual development and strengthens the formation of probabilistic–statistical thinking skills, which occupy a central place in their practical activities.

Although the principle of continuity requires the interconnection of stages of scientific development in a coherent manner, its implementation necessitates the creation of specific didactic conditions and methodologies for ensuring continuity for each field of study. In higher education, continuity is understood as a process that, based on constant interrelations between individual stages and levels, ensures students' professional development, the improvement of their general and professional competencies, and a deeper comprehension of the knowledge acquired at each stage of education. Ensuring the continuity of education implies a transition to a new qualitative level, recognition of the importance of education for both society and the individual, orientation toward the active mastery of methods of acquiring knowledge, alignment of the educational process with the learner's needs and demands, and the expansion of individual capabilities through learner-centered education. In addressing these issues related to the principle of continuity, taking into account the ongoing renewal of educational goals and methods, it is considered an urgent task to improve the methodology of teaching physics by ensuring coherence and continuity between its stages of development through the use of innovative didactic and computer technologies.

As is well known, continuity in lifelong education represents a system of developing sequentially interconnected stages as a unified whole, creating conditions for the advancement of each level to a higher degree of development. According to the principle of developmental teaching, ensuring coherence in the transition from simple to complex plays an important role in enhancing thinking and knowledge acquisition abilities, as well as in shaping a scientific worldview.

The role of continuity between molecular physics and quantum statistics in the growth and development of science has been expressed by several great physicists through various analogies. In particular, A. Einstein emphasized the holistic development of scientific knowledge by stating: *"When forming new scientific ideas, we must examine old ideas and theories, even if they belong to the past, because they are the only means of understanding and determining the limits of application of new ideas"* [4].

The subject of molecular physics includes the study of the forms of motion of molecules and the collective motion of a large number of molecules. In this context, there are two equally important aspects of study. The first concerns the characteristics of the forms of molecular motion, while the second involves mastering methods for studying systems of a large number of particles using appropriate concepts. The latter encompasses a much broader field, including not only the forms of molecular motion, but also methods for describing the states of particles through the specific concepts of statistical physics and thermodynamics. In teaching molecular physics, it was initially considered as a branch of physics with primary emphasis on the forms of motion of molecular systems. Later, with the emergence of new concepts, the development of new theories based on statistical laws and thermodynamic methods elevated the study of molecular systems to a higher and more refined level.

For a gas consisting solely of electrons, the energy distribution is determined using the Fermi–Dirac distribution, while for a gas of photons with integer spin, the Bose–Einstein distribution is applied. In this framework, all particles with half-integer spin are classified as fermions, and particles with integer spin are classified as bosons, and their energy distributions are theoretically substantiated through corresponding universal distribution functions.

Because the energy distributions determined by quantum statistics take into account the nature of particles with high precision, they enable the understanding of many practical problems. For example, by treating free electrons in metals as an electron gas with half-integer spin and calculating them according to the fermionic distribution, it was established that electrons possess discrete energy levels up to the Fermi level. This led to the emergence of the quantum theory explaining the electrical and other properties of metals. Similarly, the study of the distribution function of gases composed of photons with integer spin laid the foundation for the theory of superfluidity. In limiting cases, that is, when the individual restrictions in the Boltzmann, Fermi–Dirac, and Bose–Einstein distribution functions in quantum statistics are gradually removed, one can observe that the Fermi–Dirac distribution transforms into the Bose–Einstein distribution, and in the absence of all restrictions, it naturally reduces to the classical Maxwell distribution. This is one of the most vivid demonstrations of the realization of the principle of continuity [5].

Indeed, according to the principle of continuity, any new theory, if it is a correct one, must naturally reduce to the old theory in limiting cases. The fulfillment of this principle is of great importance in physics. When students conduct scientific research or solve complex problems, they can verify whether they are on the right path by checking whether the principle of continuity holds for the resulting formulas in limiting cases. These considerations show that the topics of quantum physics demonstrate the progression from simple to complex in the study of the laws of nature, while the principle of continuity emphasizes the necessity of studying them as an interconnected whole in order to deeply comprehend their internal essence.

Summarizing the above ideas, continuity can be defined as follows: "Continuity in teaching expresses the connection between the stages of development of knowledge, skills, and competencies; that is, the knowledge acquired at the initial stage of instruction is preserved and applied in acquiring new knowledge at subsequent stages. Previous and subsequent knowledge are integrated into a single coherent whole." Thus, the above discussion once again confirms the importance of ensuring coherence and continuity in physics education during the teaching process.

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