



DIDACTIC FOUNDATIONS OF INTEGRATING PHYSICS INSTRUCTION BASED ON A SYSTEMATIC APPROACH

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Abstract: *Background. The integration of physics and chemistry in higher education plays a crucial role in developing students' professional competencies. For chemistry students, physics provides a fundamental basis for understanding molecular processes, energy transformations, and the physical laws governing chemical reactions.*

Aim. *This study aims to substantiate the scientific and methodological foundations of teaching physics to undergraduate students of chemistry based on a systematic approach.*

Methods. *The research is grounded in systemic analysis, pedagogical design, and interdisciplinary integration. The principles of physics and chemistry are examined through their common laws, theoretical frameworks, and practical interrelations.*

Results. *The findings demonstrate that a systematic approach fosters deeper comprehension of physical laws and enhances students' ability to apply theoretical knowledge in solving chemistry-related problems. The molecular kinetic theory of gases is presented as a case study to illustrate effective pedagogical mechanisms.*

Conclusion. *The proposed methodology ensures a natural integration of physics and chemistry, strengthens interdisciplinary understanding, and contributes to the professional development of chemistry students at the undergraduate level.*

Keywords: *Physics teaching methodology; systematic approach; chemistry education; interdisciplinary integration; molecular kinetic theory of gases.*



INTRODUCTION

In modern higher education, the integration of natural sciences is emerging as an important methodological approach. In particular, the systematic teaching of interrelated disciplines such as physics and chemistry enables the formation of interdisciplinary knowledge, the development of analytical thinking, and the deepening of professional competencies among students. Chemistry and physics, when integrated, provide complementary explanations of natural processes: while physics analyzes the motion of molecules and their energetic foundations, chemistry studies the transformations of substances that result from these molecular interactions.

Physics and chemistry, as systems of scientific-theoretical knowledge that study matter, energy, and their interaction mechanisms, are inherently interconnected. They logically complement and reinforce each other in understanding complex natural phenomena. Therefore, teaching these subjects on an integrative basis not only enhances the level of knowledge acquisition among students but also fosters analytical thinking, cognitive skills, and functional literacy. This, in turn, promotes a systemic and competency-based approach aimed at solving complex real-life problems.

“Physical chemistry is the philosophy of chemistry,” as noted by M.V. Lomonosov, emphasizing the profound interconnectedness of these two sciences in reflecting the scientific picture of the universe.

The relationship between physics and chemistry is most clearly manifested in their common scientific objects—such as the structure of matter, energy exchange, phase states, equilibrium conditions, and kinetic processes. Applying this integration to the educational process allows the microstructure of matter, energetic reactions, and both statistical and experimental methods to be explained in harmony. Such an approach enables students to develop complex thinking and strengthen their analytical competencies.

Physics, as one of the fundamental sciences, serves as a foundation for chemistry education, providing deeper insights into the essence of many natural processes. Therefore, for students of chemistry, the physics course should be taught in a specific way that not only imparts general scientific knowledge but also reinforces and deepens chemical understanding. This justification can be effectively illustrated through the application of a Venn diagram.

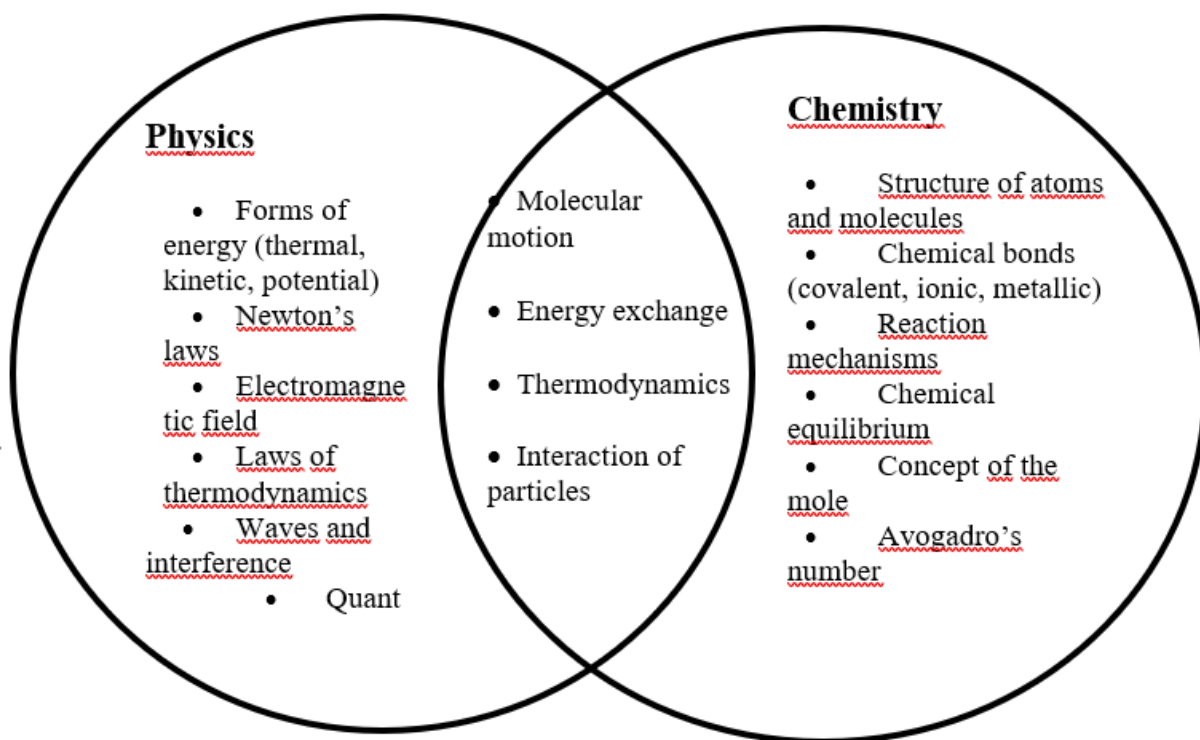


Figure 1. Explanation of the common and distinctive aspects of physical and chemical concepts using a Venn diagram.

This diagram provides an understanding of the interrelation between physics and chemistry in teaching physics to chemistry students and allows for distinguishing their essential features.

The Fishbone (Ishikawa) diagram technique is based on differentiating and naming the components of a lesson, along with giving short answers regarding their definitions, content, and practical aspects. At the head of the fish, the name of the subject is written; on one side of the spine, questions related to the parts and key aspects of the subject are placed, while on the opposite side, the corresponding answers are written. Based on these question–answer pairs, the key features of the lesson are revealed. At the tail of the fish, the conclusions about the lesson are recorded. In general, the application of the fishbone diagram as an example of introducing interdisciplinary integration is illustrated in Figure 3.

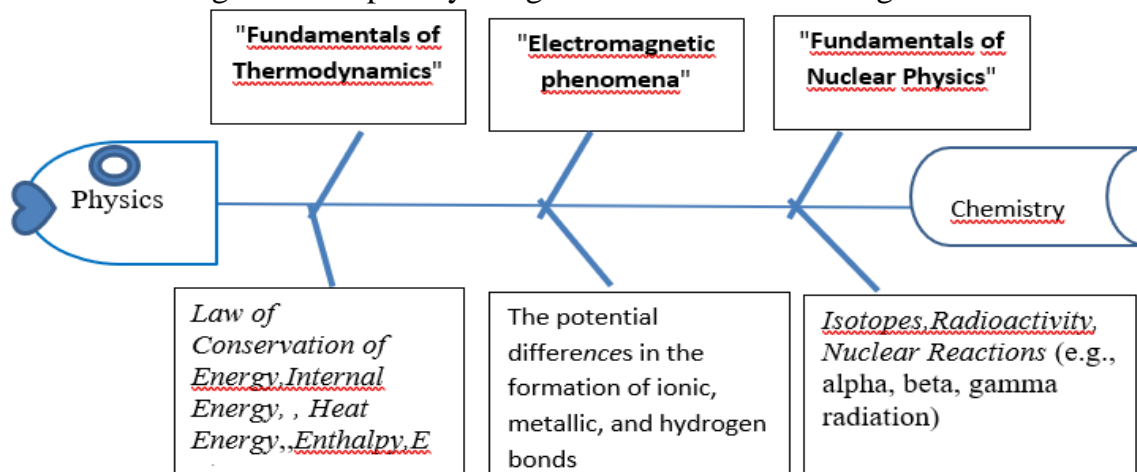


Figure 2. Integration of Physics with Chemistry

The proposed fishbone pedagogical technology provides descriptive and classificatory information about the integration of physics teaching for chemistry students.

Below, the most important topics in physics that require special attention are analyzed (Figure 3). For example, “Structure of Matter and the Laws of Molecular Physics” is essential for chemistry students to understand that intermolecular forces, diffusion, and the physical properties of gases, liquids, and solids depend on their microscopic structure. These topics, particularly the gas laws, the equation of state, and the ideal gas model, play a crucial role in understanding chemical reactions (e.g., changes in volume, pressure, and temperature in ideal gases).

The “Fundamentals of Thermodynamics” – including the law of conservation of energy, internal energy, heat, enthalpy, and entropy – are among the core topics in physics. This section provides the theoretical foundation of chemical thermodynamics. For instance, understanding endothermic and exothermic reactions and their relation to heat exchange is impossible without mastering these concepts.

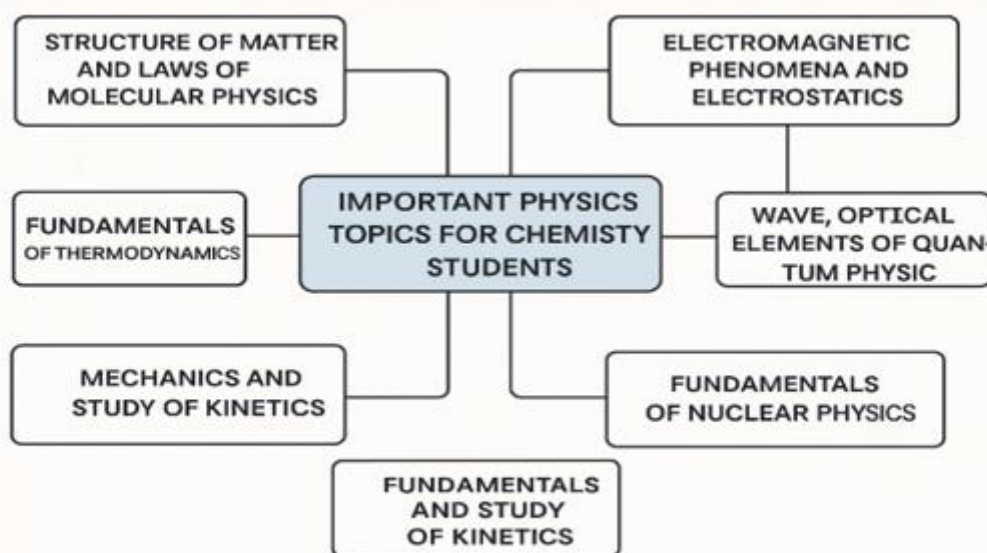


Figure 3. Integration of Physics Topics for Chemistry Students

“Electromagnetic phenomena and electrostatics” are essential for understanding the nature of chemical bonds, particularly the formation of ionic, metallic, and hydrogen bonds, which depend on the relationship between electric forces, charges, and potentials. Concepts such as electrolysis, galvanic cells, and electrochemical potential are studied based on knowledge derived from physics.

“Waves, optics, and elements of quantum physics” are crucial for properly comprehending chemical concepts such as spectroscopy, atomic and molecular energy levels, quantum numbers, and electron configurations. In this regard, knowledge about the wave and quantum properties of light is necessary. For example, the photoelectric effect, spectral lines, quantum energy, and types of electromagnetic radiation are of great importance.

“Fundamentals of nuclear physics” are needed to study isotopes of chemical elements, radioactivity, and nuclear reactions (e.g., alpha, beta, and gamma radiation), as well as their

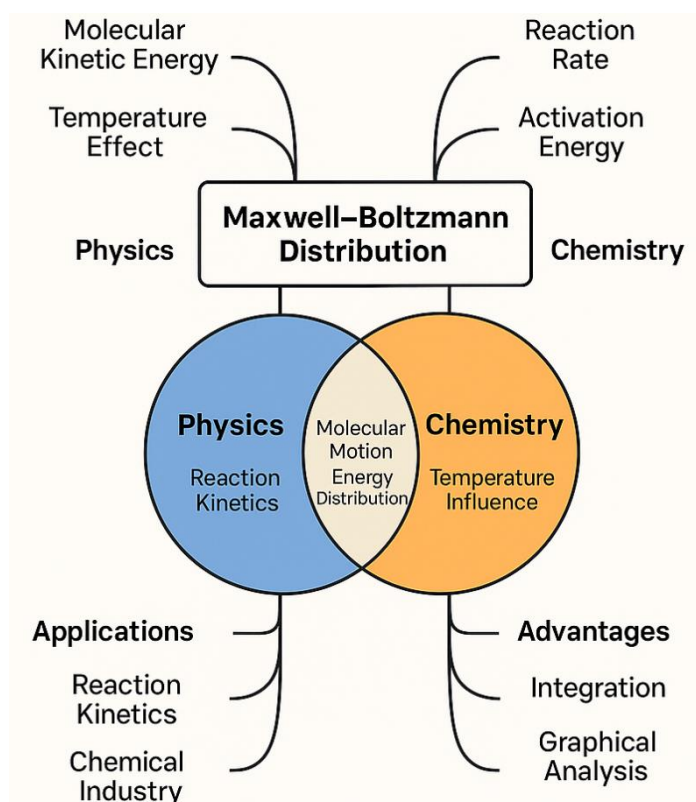
energetic and safety aspects. This is particularly important in fields such as radiochemistry, environmental protection, and the use of isotopes in medicine.

“Study of mechanics and kinetics”, although not a core discipline of chemistry, plays a central role in understanding the principles of laboratory equipment operation and the relationship between reaction rates and the kinetic motion of particles. In particular, Newton’s laws and concepts such as impulse, force, and pressure are essential in laboratory experiments.

The above-mentioned physics topics are of decisive importance in strengthening the theoretical foundations of chemistry, deepening scientific concepts, understanding interconnections, and applying them in practice. Therefore, physics should be taught to chemistry students through an integrative approach, i.e., in close connection with corresponding concepts in chemistry. This method helps students develop analytical thinking, scientific reasoning, and interdisciplinary integration skills.

In addition, the molecular kinetic theory (MKT) of gases is a fundamental topic located at the intersection of physics and chemistry. It explains macroscopic parameters (pressure, temperature, density) through the statistical motion of particles in the gas phase. This theory forms the scientific foundation of modern chemical kinetics, thermodynamics, and technological processes.

The integration of physics and chemistry can be further illustrated through the Maxwell–Boltzmann distribution as follows:



Maxwell–Boltzmann Distribution is a statistical law that describes how the molecules of an ideal gas are distributed at different speeds. This distribution is especially important for understanding how molecular kinetic energy depends on temperature.

As can be seen from the graph, not all molecules move at the same speed. Instead, most of them cluster around an average speed — this is the most probable speed, statistically the most likely state. The curve rises sharply on the left and then gradually decreases on the right. As temperature increases, the peak of the curve shifts downwards and to the right (meaning that the average speed of molecules increases). With increasing temperature, the kinetic energy of molecules grows and the distribution becomes more “stretched out.”

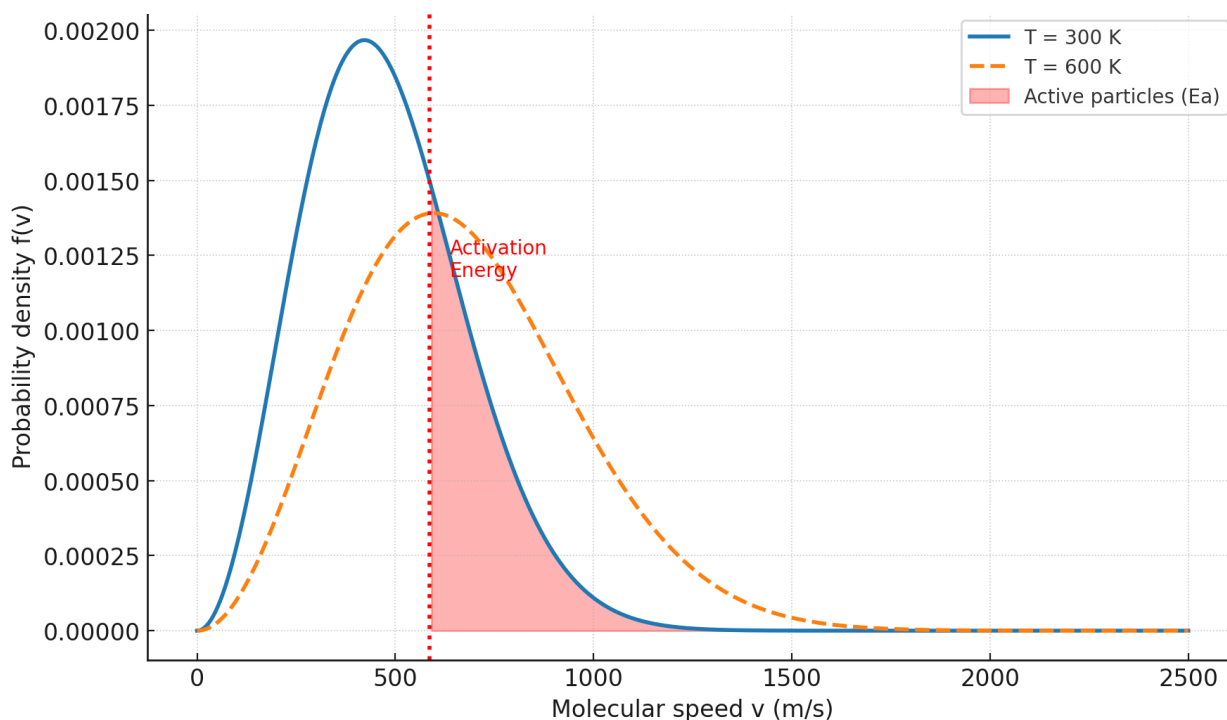


Figure 1. Maxwell–Boltzmann velocity distribution graph ($T = 300$ K).

The Maxwell–Boltzmann distribution function is given by the following expression:

The Maxwell–Boltzmann distribution plays an important role in determining the fraction of active particles in gas kinetics, namely:

- For a reaction to occur, particles must have energy greater than the activation energy.
- On the distribution graph, this region corresponds to the “tail” at higher velocities.

According to the theory of chemical kinetics, the reaction rate depends precisely on the number of molecules in this high-velocity region.

Thus, the Maxwell–Boltzmann distribution provides the opportunity to model physical and chemical processes from a statistical perspective. Especially for chemistry students, this graph serves as a key scientific tool in analyzing reactions, estimating the fraction of active particles, and explaining the effects of temperature and pressure.

Teaching physics to chemistry students based on a systematic approach is a practical expression of interdisciplinary integration. By combining the physical and chemical foundations of the molecular kinetic theory of gases, students not only deepen their theoretical knowledge but also acquire skills to apply it in chemical technologies. This, in turn, contributes to the development of their professional competencies. Therefore, physics–

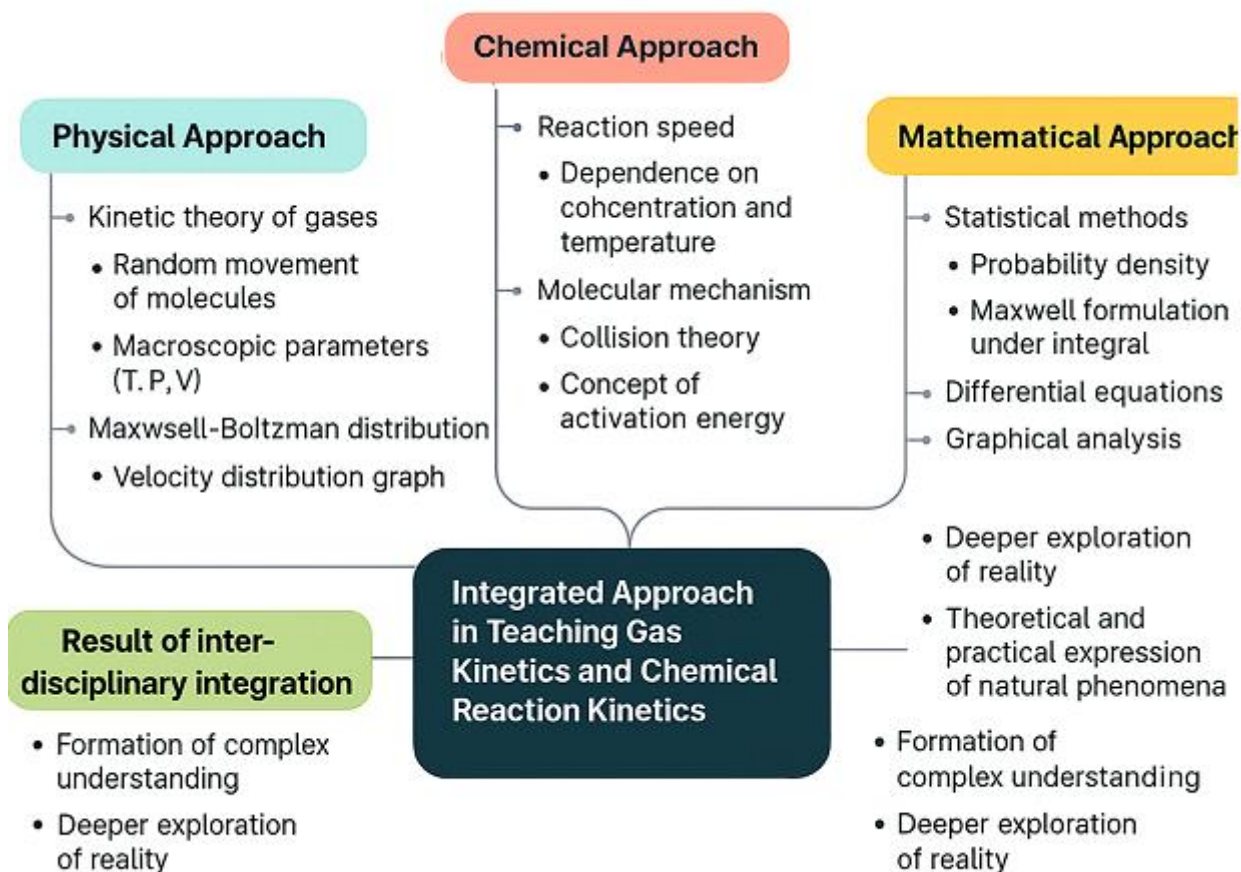
chemistry integration holds a significant place among modern pedagogical strategies, fostering systematic, analytical, and complex thinking in students.

In the study of real gases, the harmony between physics and chemistry is of great importance. In particular, the Van der Waals equation makes it possible to account for intermolecular forces and molecular volume in real gases. This is necessary for correctly interpreting thermodynamic processes and analyzing the dynamics of gas mixtures.

The frequency of molecular collisions and the effectiveness of these collisions directly affect the rate of chemical reactions. This phenomenon represents one of the key boundary problems reflecting the close relationship between chemical kinetics and molecular physics. Such processes allow the mechanisms of reactions at the molecular level to be understood. Therefore, when teaching chemistry students the topic “Fundamentals of the Molecular Kinetic Theory of Gases”, it is necessary to explain this theory in an integrated way with chemical processes.

The educational significance of the topic lies primarily in revealing the direct relationship between the rate of gas-phase reactions and microscopic factors — molecular motion, their kinetic energy, collision probability, and geometry. Consequently, by studying this theory, students not only gain a deeper understanding of physico-chemical phenomena but also develop the ability to model reactions and predict their rates. Organizing the learning process on a scientific basis enables the formation of students’ systematic and integrative knowledge of natural sciences. This, in turn, teaches them to use modern analytical and modeling methods. Such an approach plays an important role in shaping and developing students’ professional competencies.

Therefore, in teaching this topic, the integration of physical, chemical, and mathematical approaches in a comprehensive manner represents one of the most effective methods. For example: ...



Teaching the molecular-kinetic theory of gases to chemistry students should be organized on the basis of a systematic and interdisciplinary approach, since this theory serves as a fundamental scientific basis for a deep understanding of chemical reaction kinetics and processes occurring in the gas phase. The results of the research, which analyzed the scientific-theoretical foundations, methodological approaches, and practical effectiveness of teaching physics to chemistry students through a systematic approach, show that such a methodology contributes to the development of students' competencies in several directions: comprehensively understanding theoretical knowledge, explaining it in connection with chemical processes, and practically applying interdisciplinary integration of natural sciences.

Moreover, methodological recommendations revealing the intrinsic interrelation between physics and chemistry, as well as the application of systematic, logical, sequential, and step-by-step approaches in designing the educational process, play an important role in developing students' scientific thinking and analytical reasoning skills. The methodological model and recommendations developed during the study broaden the possibilities of effectively teaching physics within the framework of chemistry education. They also lay the groundwork for improving the quality of professionally oriented education by reinforcing an interdisciplinary integrated approach.

Therefore, implementing this methodological approach and applying the recommended pedagogical technologies in pedagogical practice meet the modern requirements of teaching physics and chemistry in a harmonized and integrative manner.



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