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Development of a Methodological Model for Teaching Physics to Technical University Students Based on the Methods of Scientific Cognition

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Abstract
In this article, the methods of effective use of the methods of teaching physics to future engineers in higher education institutions are discussed. In addition, potential engineers have been shown ways of developing their professional activities such as design, construction, through the use of educational methods in lectures, practical, laboratory and practical training.

Key words: Scientific cognition, empirical cognition, animation, rational cognition, methodology, conceptual, technology, design.

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Introduction. Comprehensive reforms are currently being implemented in the education system of the Republic of Uzbekistan. In particular, the Concept for the Development of the Higher Education System of the Republic of Uzbekistan until 2030 (Presidential Decree No. PF-5847, dated October 8, 2019) outlines the priority directions for systematic modernization of higher education. The document emphasizes the need to elevate the training of highly qualified specialists capable of independent thinking, equipped with modern knowledge, and possessing strong moral and ethical values to a qualitatively new level. It also defines measures aimed at modernizing higher education and promoting the development of social sectors and economic industries through the introduction of advanced, technology enhanced educational practices [1].

The initial stage in the development of physical concepts involves direct acquaintance with the objects, phenomena, and processes of the material world surrounding us. This stage fundamentally consists of observing physical phenomena and processes individually, studying them, conducting experiments, and identifying their essential and characteristic features. Such acquaintance, observation, and experimentation may occur at different points in time. If these actions were performed earlier, the resulting knowledge forms a reconstructive scientific understanding of the phenomenon. If they occur in the present moment, the foundation of this understanding lies in sensory experience perception, analysis, and synthesis of empirical information [2].

As noted above, from a gnoseological perspective, the stages of scientific and educational cognition may be conceptualized as a continuous chain extending from singularity to generality: beginning with experimental data and empirical laws, progressing toward the fundamental laws

expressed as axioms of a physical theory, and ultimately reaching limiting generalizations that describe specific physical systems. The substantive structure of a physical theory, in this sense, is epistemologically analogous to this sequential process of scientific and educational cognition.

In practical scientific and pedagogical activity, this gnoseological chain is realized through the combined use of empirical and theoretical methods of inquiry. Empirical methods are directed toward describing concrete scientific facts by means of inductive generalization based on experimental evidence. The classical gas laws, formulated on the basis of empirical observations, serve as illustrative examples of such inductive generalizations. Theoretical methods, in contrast, enable the identification of fundamental cause effect relationships within the studied domain, employing not only formal logical procedures but also dialectical reasoning to reveal deeper structural connections [3].

Literature Review. The development of molecular physics and thermodynamics encompasses a wide spectrum of scientific progress from the study of mechanisms of energy transfer and the transformation of one form of energy into another to the description of dissipative systems and nonequilibrium processes. Similarly, the evolution of physical thinking has traversed a path from the characterization of mechanical motion to the formulation of quantum mechanics, where phenomena are interpreted through mathematical constructs and abstract models.

In the investigation of thermal phenomena, two principal scientific approaches can be distinguished:

The discovery of the law of conservation and transformation of energy in physics is traditionally attributed to J. Joule, R. Mayer, and H. Helmholtz. In 1850, the second law of thermodynamics was first formulated as an empirical principle by R. Clausius, followed by W. Thomson (Lord Kelvin) in 1851. Clausius introduced into physics the concepts of internal energy and the thermodynamic quantity later known as entropy [4]. Subsequently, the first and second laws of thermodynamics came to be regarded as the fundamental principles governing thermodynamic systems. The molecular–kinetic interpretation of thermodynamics was further advanced through the seminal works of Boltzmann and Gibbs, whose contributions laid the theoretical foundations of modern statistical physics [5].

In recent decades, a third stage in the development of thermodynamics has emerged, marked by the rise of nonequilibrium thermodynamics and the physics of dissipative systems, largely associated with the works of I. Prigogine [6]. Thermodynamics has thus evolved into a coherent phenomenological theory that characterizes energy transformations in their most general form across a broad range of natural processes [7].

The systematic nature of a physical theory whether representing scientific knowledge or serving as an educational framework is determined by the structural and systemic properties of the segment of reality it describes. From a methodological standpoint, it is essential to recognize that any physical theory, including thermodynamics, constitutes a conceptual system of scientific and pedagogical cognition.

Research Methodology. The methodological task of developing the substantive scientific knowledge embedded in physical theories must be grounded in a systemic approach. Within the learning process, a physical theory and the theoretical and practical problems associated with it should not be treated as a fragmented set of ideas, concepts, or instructional guidelines directed toward professional practice. Instead, it must be studied as an integrated system of scientific knowledge, with full consideration given to the systemic properties of the theory itself. This approach requires the implementation of interdisciplinary, integrative instruction that ensures the coherent and structured assimilation of physical concepts and theoretical constructs [8].

The concept of management in scientific and pedagogical-psychological literature is interpreted as the functional unity of subsystem and supersystem elements of various natures biological, social,

technical, and physical—that possess an organized and planned structure. This unity ensures the implementation of a system's professional activity plan as well as the achievement of its professional goals and objectives, taking into account the specific structural characteristics of the system involved [9].

In the context of engineering bachelor's education, it is advisable to organize and support students' learning processes through a methodological framework that incorporates principles, approaches, and regularities responsible for regulating and guiding students' cognitive activity. Such a framework also facilitates the development of their professional competencies in accordance with normative-legal requirements.

Any process of organization and development reflects the internal order and coherence of the whole, determined by the structure of its components and the integrity of their interrelations. As an evolving process, the organization and development of competencies consist of a set of meaningful actions that establish communicative and functional connections among the parts of the whole, thereby ensuring continuous improvement and growth [9].

According to Deming's cycle, management theory divides the organization of any process into four essential components:

a) Goal component: defining objectives and tasks, and determining the strategies, methods, and pathways necessary to achieve these goals;

b) Process component: carrying out the planned instructional or operational activities;

c) Diagnostic component: assessing and evaluating the results of the completed activities;

d) Outcome component: implementing corrective actions based on identified shortcomings and feedback.

Grounded in the objectives of learning and the structure of the Deming cycle, a methodological model for managing students' learning processes in molecular physics and thermodynamics can be developed for technical higher education institutions (Figure 1). This model ensures the systematic regulation of students' cognitive activity and enhances the efficiency of learning by integrating continuous improvement principles.

The goals of higher education are determined by the needs of society and the state. Within this framework, the overarching objective is to foster the comprehensive professional development of future engineers, particularly through the cultivation of discipline-specific competencies via physics education.

In alignment with higher education goals, the formation of physical knowledge must proceed in a systematic manner, supporting both the development of professional competencies and the establishment of a scientific worldview oriented toward educational and professional objectives. The developmental goals of higher education, in turn, emphasize the formation of analytical thinking, intellectual independence, and the ability to apply conceptual knowledge to real-world engineering contexts [10].

The classification of educational goals by their final outcomes implies that, for an engineering student, the ultimate aim becomes achieving a high level of professional competence. For the professor or instructor, however, the primary goal is to guide the future engineer toward becoming a true specialist—one capable of independently solving professional, practice-oriented problems—by carefully selecting and applying appropriate instructional tasks. The consistent implementation of this algorithmic sequence of goals ensures full alignment with the broader objectives of engineering education [11, p. 30].

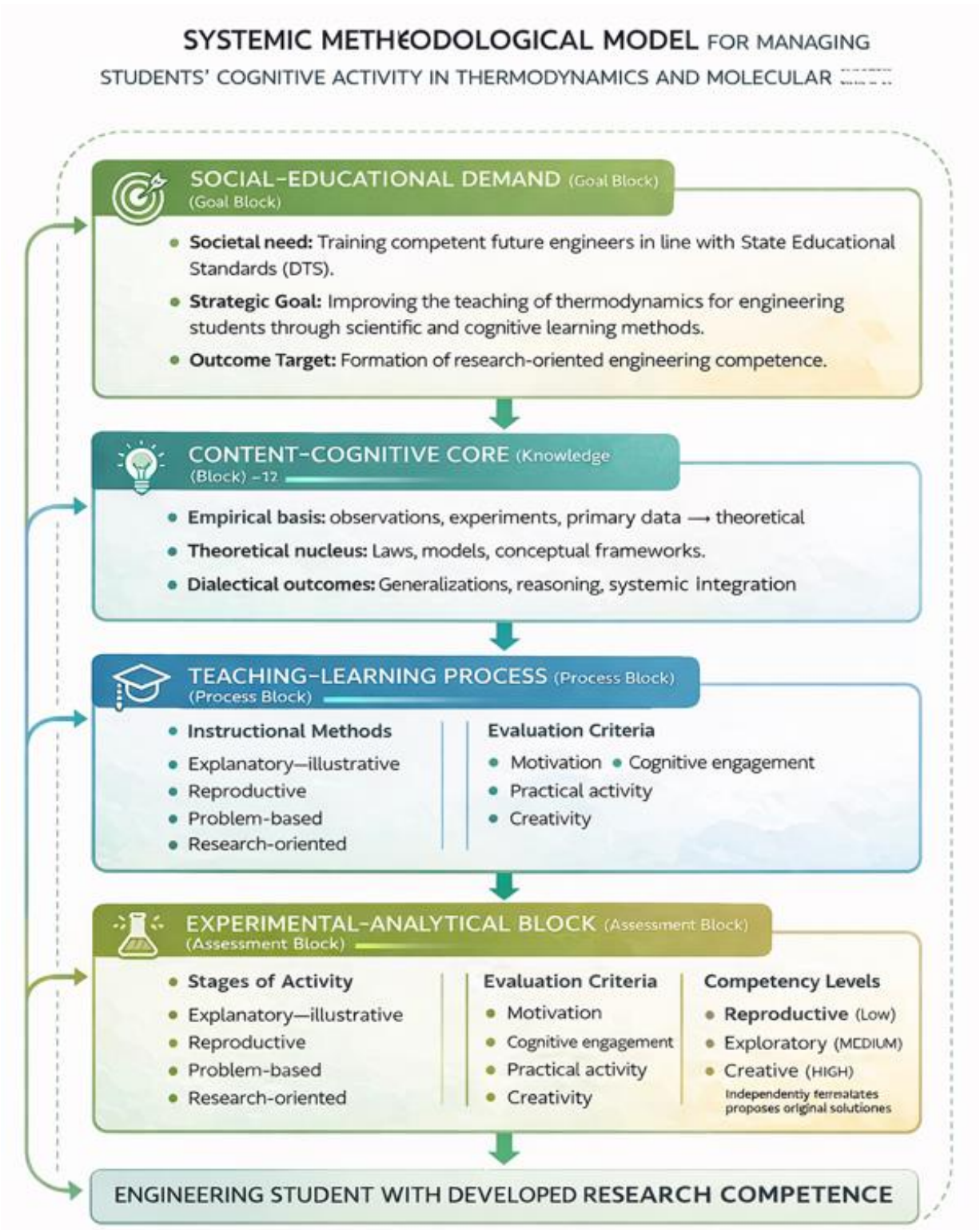

Figure 1. Methodological model for managing students" cognitive learning processes in teaching thermodynamics at technical higher education institutions

Such goals contribute to the development of synergistic and equally significant opportunities for both learners and instructors. In other words, the traditional "object–subject" model of instruction transforms into a "subject–subject" interaction between teacher and student, as described by S. I. Yakimanskaya and E. V. Bondarevskaya [9].

In the model of managing students' cognitive learning, this communicative interaction is illustrated in Figure 1. Within a subject–subject communicative framework, the professor or instructor manages the cognitive learning processes of future engineers. However, effective management requires a deep understanding of the communicative connection between singularity, generality, and limiting generality—that is, the relationship between the empirical foundations, theoretical core, and deductive (dialectical) outcomes of a fundamental physical theory and the scientific and educational methods derived from it.

In our view, if the substantive (content-related) and procedural aspects of cognitive learning are aligned with one another on the basis of the competency-based approach and the principle of continuity, these components will not only facilitate diagnostic assessment but also ensure the correction and refinement of learning outcomes. As a result, they contribute significantly to the overall effectiveness of the management process.

To achieve the core objectives of teaching physics, it is essential to follow the algorithmic sequence outlined below:

– selecting an effective cognitive-learning technology that integrates instructional methods (explanatory–illustrative, reproductive, problem-based exposition, heuristic, research-oriented), teaching formats (lectures, seminars, laboratory work), and instructional tools (verbal, visual, specialized, technical, and computer-based resources);

– managing cognitive learning with a high degree of pedagogical mastery. In accordance with the logical structure of scientific cognition, the requirements related to the empirical basis of physics, its theoretical core, and its deductive outcomes must be fully demonstrated (thus ensuring the preparation of a competent engineer); at the same time, diagnostic evaluation must be carried out at every stage of the learning process, followed by the implementation of subsequent stages of acquiring physical knowledge [10].

Analysis and Results. The methodology developed in this study for forming essential professional competencies in engineering students through the teaching of physics is grounded in scientific and educational methods of cognition. The implementation is carried out across different instructional formats as follows:

1. ***Lectures (Methodological Level – Theoretical Core).*** The reproductive method is employed to assess and enhance students' creative engagement in acquiring new concepts, phenomena, and laws. This method supports the consolidation of theoretical material, enables direct management of cognitive activity, facilitates rapid identification of gaps in understanding, and contributes to the development of practical skills and competencies essential to engineering education.
2. **Laboratory Work (Methodological Level** – Empirical Foundation). The explanatory–illustrative method is used to cultivate students' design and construction competencies. For example, the instructor demonstrates laboratory techniques and experimental procedures, allowing students to acquire hands-on skills and observe empirical manifestations of theoretical principles.
3. **Practical Sessions (Methodological Level – Empirical Foundation).** The problem-based exposition method is applied to stimulate students' scientific inquiry, activate intellectual abilities, and foster their capacity for independent reasoning. Through this method, learners are guided to identify, analyze, and solve conceptual and applied problems.
4. **Independent Learning (Gnoseological and Didactic Level – Dialectical Outcome).** The project method is used in independent study to develop students' abilities in scientific inquiry. By creating pedagogical software products or solving project-based tasks, students strengthen their competencies in design, construction, and engineering problem-solving.

5. **Academic Clubs / Research Groups (Gnoseological and Didactic Level – Dialectical Outcome)**. The research method serves as the culminating stage in preparing students for scientific and engineering research. Within the framework of structured scientific projects, students undertake a sequence of research-oriented activities, including:

Observation: Studying industrial enterprises, production potential, geographic location, and climatic conditions.

Experimentation: Collecting samples from industrial zones and conducting field investigations.

Measurement: Analyzing the composition of collected samples using specialized laboratory equipment.

Analysis: Examining measured data to determine structure, composition, and key characteristics.

Synthesis: Identifying the interactions and relationships between the components of the samples.

Formalization: Applying mathematical models and formulas to describe the obtained results.

Modeling and Automation: Integrating formalized outcomes into functional computational models; programming the modeled processes on a computer; generating tabular and graphical output; and preparing scientific presentations of the results.

Summary and Suggestions. The study demonstrates that teaching physics as a fundamental physical theory to future engineers is most effective when implemented through a well-structured methodological model. This methodological system encompasses four interrelated components: goal-oriented, content-oriented, process-oriented, and diagnostic.

The **goal-oriented component** reflects the societal demand for preparing competent future engineers, as well as the requirements defined in higher education state standards and qualification frameworks.

The **content-oriented component** is shaped by methodological, gnoseological, and didactic methods of scientific cognition, ensuring alignment between theoretical principles and educational content.

The **process-oriented component** involves the selection and application of appropriate teaching methods, forms, and instructional tools, reflecting the dynamics of the educational process.

The **diagnostic component** provides opportunities to evaluate the effectiveness of learning outcomes and reveals the communicative interdependence between the content-related and process-related elements of the model.

Taken together, these components form a coherent methodological framework that supports the systematic development of professional competencies in engineering students through the structured study of physics.

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