WAYS TO OVERCOME DIFFICULTIES IN LEARNING PHYSICS

INTRODUCTION

The physical knowledge of a modern engineer must meet the requirements of fundamentalism, professionalism and technology. Physics is the foundation of technical sciences, which should be taught in accordance with the future profession. The teaching of Physics should be carried out in the form of the teaching technology. Research shows that the current teaching methodology of Physics does not fully meet the so-called requirements. The shortcomings are as follows:

1. The growing innovations of theoretical and applied physics are constantly increasing the volume of teaching material, making it difficult to understand. The duration of education remains unchanged or decreases. The current teaching methodology does not meet the requirement of teaching large and complex topics.

2. Concepts and terms of technical disciplines and Physics vary, using different symbols, laws and equations. In these subjects, physical quantities and their units often do not resemble each other.

3. Physics should be a source of basic knowledge that allows to understand the unbalanced open systems, the existence of self-organized and spontaneous antidissipative processes in systems, synergistic effects, the operation principle of "alternators" working on "fuelless" and field types of energy, the principle of nanomaterials production. These important issues related to modern equipment and technology cannot be included in the content of existing Physics programs.

4. The existing methodology allows to memorize the teaching material mechanically, without comprehension. This does not permit the formation of solid, long-term knowledge that is important for the study of specialty subjects.

5. In the current methodology, the tendency to study the subject of Physics exclusively is a real advantage.

6. This situation has emerged due to the fact that such notions as material point, conservative system, instantaneous speed, and others were introduced to Physics through Mathematics. For example, the concept of “material point” is a mathematical abstraction. In this case, the spatial dimensions of the object are conditionally reduced to zero. This means that there is no external frictional resistance during the movement of the material point. In addition, the lack of spatial dimensions makes senseless the rigidity of the system. Finally, the material point does not have the form of rotational motion.

These shortcomings can be overcome by implementing new approaches in the teaching of physics and making changes in its content and structure. In our opinion, the above-mentioned difficulties can be overcome by using modern theories and laboratory experiments in the teaching of Physics and by applying analogy as a method and tool. Mainly based on this idea we have created the system of teaching Physics with a Unified Approach (SAFAROV; VALIEV, 2013; SAFAROV, 2014). This system is created through ization of different groups of physical analogues for the same forms of movement.
METHODOLOGY OF CREATING A SYSTEM OF TEACHING PHYSICS WITH A UNIFIED APPROACH

The teaching of Physics is a process. The main condition for a process to be a system is that it consists of interrelated stages. Therefore, we divided the process of teaching Physics into stages (Table 1).

Table 1. Stages of teaching Physics

| No. | Stages |
|-----|--------|
| I.  | Determination of the forms of interaction (movement) included in the content of Physics |
| II. | Definition of properties with extensiveness attributes (CENGEL; BOLES, 2006) for each form of motion and itsation of the extensive property for all forms of motion |
| III. | Determination of properties with intensity attributes (CENGEL; BOLES, 2006) for each form of motion and itsation of the intensive properties for all forms of motion |
| IV. | Determination of an equilibrium criterion for individual properties and itsation of these criteria. Determination of the moment of distribution of the extensive quantity (Z) as an absolute extensive measure of the spatial heterogeneity of the system (ETKIN, 2011) by one of the properties, generalization of the moment of distribution of an extensive quantity. Analyzing the expression for the total differential of the function Z for one form, all processes occurring in inhomogeneous systems can be separated into three groups: even, redistributing and reorienting. Generalization of this provision for all forms of movement. |
| V.  | Determination of the expression of forces proportional to the potential gradient, taking into account that the reason for the occurrence of processes in the system is the potential gradient on the one hand, and the force on the other. |
| VI. | Understanding work as a quantitative measure of the process associated with overcoming any forces, its definition by the presence or absence of the forces being overcome forces (ordered or disordered) (ETKIN, 2011). Determination of expressions of individual disordered works in uniform processes and their itsation. |
| VII. | Determination of expressions of individual ordered works in the processes of redistribution and reorienting, and their itsation. |
| VIII. | Accepting total energy as a quantitative measure of all ordered and disordered works that a system can perform, recording the change in total energy as a sum of ordered and disordered works, and using them: \[ dE_{total} = \sum \psi_i d\theta_i - \sum \theta_i d\psi_i \] |
| IX. | Obtaining the laws of conservation of linear and angular momentum, electric charge, total energy from the expression of the change in total energy |
| X.  | Determination of physical analogs characterizing the subsystems of capacitive, resistive and inductive behavior involved in transient processes |
| X.1 | Capacitive behavior subsystems, generalized voltage formula in capacitive behavior subsystems: \[ \psi_C = \frac{\theta}{C} \] |
| X.2 | Resistive behavior subsystems, generalized voltage formula in resistive behavior subsystems: \[ \psi_R = \frac{RI}{R} = \frac{R \dot{\theta}}{R} \] |
| X.3 | Subsystems of inductive behavior, generalized voltage formula in subsystems of inductive behavior: \[ \psi_L = \frac{L \ddot{\theta}}{L} \] |
| XI. | Transient processes. Ited differential equation characterizing the transient processes: \[ \frac{d^2 \theta}{dt^2} + R \dot{\theta} + L \dot{\theta} = \psi_C + \psi_R + \psi_L = \psi(t) \] |
| XII. | Transfer events. They are associated with a resistive subsystem that occurs during the transition process: \[ j = -k \frac{d\theta}{dt}; k \text{ - transfer coefficient.} \] |

Source: Search data.

At all stages, issues related to the same forms of movement are studied. Forms of movement "relate" the stages to each other. Each stage consists of elements - physical analogues (Table 2). By physical analog, we mean physical objects (quantities, formulas, etc.) that have at least one same physical property. The stages form one group of physical analogs, while the elements within the stage form another group of physical analogs.
Table 2. Intra-stage elements of teaching Physics

| Stage          | Intra-Stage Elements |
|----------------|----------------------|
| I. Motion forms| 1. Straight-line motion. 2. Rotation around the fixed axis. 3. Laminar flow, gas flow. 4. Mass exchange. 5. Moving the mass in the gravitational field. 6. Heat exchange. 7. Electrical interaction. 8. Magnetic interaction. |
| II. Extensive properties (\(\Theta_i\)) | 1. Linear momentum projections (\(p_x, p_y, p_z\)). 2. Angular momentum projections (\(L_x, L_y, L_z\)). 3. Liquid volume (V), gas volume (V). 4. Substance change (N). 5. Body mass (M). 6. Entropy (S). 7. Electric charge (q). 8. "Magnetic charge" (qv) |
| III. Intensive properties (\(\Theta_i\)) | 1. Projections of the linear velocity (\(v_x, v_y, v_z\)). 2. Angular velocity (\(\Omega\)). 3. Linear and gas pressure (P). 4. Chemical potential (\(\mu\)). 5. Gravitational potential (\(\phi_g\)). 6. Absolute temperature (T). 7. Electric potential (\(\phi\)). 8. Magnetic potential (\(\phi_m\)). |
| IV. Processes. | [summands I characterize uniform processes, summands II characterize redistribution processes] |
| V. Forces: \(\Theta_g\) | 1. Newton force: \(F = -\mathbf{p}\). 2. Rotating force: \(L = \mathbf{r} \times \mathbf{v}\). 3. Force acting on the liquid and gas volume element: \(V = \mathbf{F}\). 4. Force in a fuel element (dialyzer): \(F_d = \mathbf{I}\). 5. Force of gravity: \(F_g = \mathbf{g}\). 6. Thermomotive force: \(F_T = \mathbf{J}\). |
| VI. Unordered work: \(\psi_i\) | 1. Work of input of a linear momentum into the body with an average speed \(v\). 2. Work of input of an angular momentum into a body with an angular velocity \(\omega\). 3. Uniform injection of liquid, expansion of gas \(P\). 4. Work of input of a substance into the system (mass transfer) \(\mu\). 5. Work of input of mass into a gravitational field with an average potential \(\phi\). 6. Heat transfer \(T\). 7. Work of input of an electric charge into an electric field with an average potential \(\psi\). 8. Work of input of a "magnetic charge" into a magnetic field with an average potential \(\psi_m\). |
| VII. Ordered work: \(\psi_i\) | 1. Work of straight-line movement of the body: \(\psi = \mathbf{F}\). 2. Work of rotation of the body around a fixed axis: \(\psi = \mathbf{L}\). 3. Work of liquid or gas flow: \(V\). 4. Work of a fuel element (dialyzer): \(\psi_d = N\). 5. Work of Movement of the mass in a gravitational field over certain height: \(\psi_g = mg\). 6. Work of the thermal engine: \(\psi_T = -\mathbf{W}\). 7. Work of dielectric polarization: \(\psi_d = \mathbf{E}\). 8. Magnetization work: \(\psi_M = \mathbf{B}\). |
| VIII. Change in the total energy of a system with five degrees of freedom | (the summands in the upper line show unordered works, and the summands in the lower line show ordered works) |
| IX. Conservation laws | 1. Conservation of linear momentum, angular momentum, electric charge. |
| X. Subsystems involved in transient processes | a) Capacitive behavior subsystems b) Subsystems of resistive behavior c) Subsystems of inductive behavior |
| X.1. Capacitive behavior subsystems | 1. \(\psi = \frac{1}{2}Cv^2\); in straight-line movement the mass is also linear momentum capacitance of the body (HERRMANN, 2000). 2. \(\psi = \frac{1}{2}J_r\); in rotation around a fixed axis the moment of inertia \(J\) is also an angular momentum capacitance of the body. 3. \(\psi = \frac{1}{2}v\); in a liquid flow in the closed pipe a capacity is defined as a change of volume which creates 1 Pa additional pressure (\(\frac{\pm}{\pm}\)). 4. Work of a fuel element (dialyzer): \(\psi_d = \mathbf{N}\). 5. Work of Movement of the mass in a gravitational field over certain height: \(\psi_g = mg\). 6. Work of the thermal engine: \(\psi_T = VdP\). 7. Work of dielectric polarization: \(\psi_d = \mathbf{E}\). 8. Magnetization work: \(\psi_M = \mathbf{B}\). |
| X.2. Resistive behavior subsystems | 1. \(\psi = -RI; R\) is the resistance to the current of the linear momentum. 2. \(\psi = -RI; R\) is the resistance to the current of the angular momentum. 3. \(\psi = -RI; R\) is the resistance determined by Poiseuille’s law, \(R\) is pipe length, and \(r\) is pipe radius (FUCHS, 2010). |
| X.3. Inductive behavior subsystems | 1. \(\psi = \frac{v}{2}\); the difference in linear velocities (voltage drop) is proportional to the rate of change of the linear momentum current (force), the inductive system is the spring, \(k\) is the stiffness of the spring. 2. \(\psi = \frac{1}{2}v^2\); the difference in angular velocities (voltage drop) is proportional to the rate of change of the angular momentum current (torque), the inductive system is the body of a physical pendulum. 3. \(\psi = -\frac{1}{2}LJ\); in a magnetic field a capacity is defined as a change of the magnetic field which creates 1 V additional voltage. |
| XI. Transient processes | 1. Discharge (from extensive property) of subsystem of capacitive behaviour (capacitor discharge): \(\psi_s + \psi_s = 0\); \(U_s + U_s = 0\) 2. Charging (with extensive property) of subsystems of capacitive behaviour (capacitor charging): \(\psi_s + \psi_s = \mu_s; U_s + U_s = 0\) 3. Disappearance of the current of extensive value in the chain of consequently connected subsystems of resistive and inductive behaviour (disappearance of the electric current): \(\psi_s + \psi_s = 0; U_s + U_s = 0\) 4. Establishment of a current (electric current establishment): \(\psi_s + \psi_s = \psi_s; U_s + U_s = 0\) 5. Free vibrations (free vibrations in a spring pendulum): \(\psi_s + \psi_s + \psi_s = 0; \left(v^2 + \frac{F_p}{m} + \frac{F_p}{P} + \frac{F_p}{P} + \frac{F_p}{P} = 0\right)\) 6. Forced vibrations (forced vibrations in a spring pendulum): \(\psi_s + \psi_s + \psi_s = \psi_s; \frac{F_p}{m} + \frac{F_p}{P} + \frac{F_p}{P} + \frac{F_p}{P} = 0\) |
| XII. Transport phenomena | 1. \(\rho = \frac{2}{3}\); Fourier’s law; 2. \(\rho = \frac{4}{3}\); Fick’s law; 3. \(\rho = \frac{4}{3}\); Newton’s law; 4. \(\rho = \frac{2}{3}\); Ohm’s law |

Source: Search data.
A system is a set of interconnected elements that together perform a common function (KRUTISKII; KOSIKHINA, 2006). It can be seen from the tables that the process of teaching Physics with a Unified Approach has a complex structure and consists of various elements. This training process has a common purpose, which is to improve the fundamental and vocational training in Physics for students of the Technical University studying at the bachelor’s level. Each element fulfills its role and function to achieve the common goal. For example, elements such as the definition of extensive, intensive properties and the ordered, unordered work associated with their changes have a special role and function. These elements are related to each other in a certain way. Elements take a certain place in society according to their role and function. The relationship between them is not arbitrary, but definite.

The arrangement of the elements connected in a certain order forms a structure. The structure is defined as an important, stable relationship between the elements of the system. Each of the elements can have their own elements in turn; for example, the training of the transition process is related to the study of elements of capacitive, resistive, and inductive nature. These elements are related to both external and internal elements. In the end, it seems that all the elements of the system are connected to each other in a certain order. These relations have their own direction, logic, and are interdependent; extensive properties and their spatial and temporal variations are included in almost all relationships. Each new element emerges as the successor of its predecessors. The arrangement of the elements in the order we describe forms a hierarchical complex structure.

Thus, the process of teaching Physics with a unified approach, which we present, has system-specific features and, therefore, is a system. This is an ideal (theoretical, conceptual) system. In this system the "forms of motion" connect the elements (stages) to each other. Therefore, the bonds of the system we have identified are, on the one hand, "forms of interaction-forms of motion" and, on the other hand, an analogy used as a method and a means. There is an analogy between the elements of the system of Physics with a unified approach and the elements of a natural tree (Table 3). This analogy gives the idea of constructing that learning process in the form of a natural tree (Learning Tree).

Table 3. Constructive analogy of the natural tree and a “Learning tree”

| Natural tree          | Learning Tree                     |
|-----------------------|-----------------------------------|
| Stem                  | Notions studied in physics        |
| Trunk                 | Motion forms                      |
| Branches              | Stages of teaching the content of Physics |
| Leaves                | Elements included in the stages   |
| Hierarchy of branches | Hierarchy of training stages       |

Source: Search data.

The construction of the learning process based on this idea (Learning Tree) is shown in Figure 1. "Forms of movement" are constructed in the form of a body and connect the learning stages and the elements within the given stage. Each branch (training stage) also connects its leaves (elements within the stage). Thus, the elements of the system we have built are connected by a double bond. The regular sequence of branches indicates the hierarchy of learning stages.

THE "LEARNING TREE" AND THE ANALOGY OF THE EVOLUTION OF A NATURAL TREE

Let us examine the evolution of the trees we have mentioned in accordance with Darwin’s principles of adaptation, variability, and inheritance. Natural tree is an unbalanced biosystem, which is located in the similar environment. The imbalance of the system causes a thermodynamic force within it. Such a force exists both within the system and in the external environment. The system is located inside the environment and they interact with each other. Therefore, the force inside the system can be balanced by the force inside the environment. This is called an external balance. Such balancing processes are responsible for the evolution of the biosystem. They are moving towards a balance between the system and the environment. External equilibrium is not a complete equilibrium (internal and external). Trying to achieve such a balance does not deprive the system of the ability to do useful work outside and convert energy inside.
In the process of balancing, the natural tree acquires new properties (new degrees of freedom). New branches and leaves appear. This is called variability. However, the changes are not accidental. Changes occur in response to environmental influences. This is called adaptation. Let us also explain inheritance in evolution. Suppose that in the biosystem, an external equilibrium is reached for any degree of freedom (a leaf of a tree has matured). This balance can be maintained for a long time. It can be passed down from generation to generation. This is called inheritance.

Let us now examine the evolution of the Learning Tree. The “Learning Tree” is an unbalanced theoretical, conceptual system. The environment for this system is the information environment necessary to provide the engineer with knowledge of physics. The information system is also unbalanced. The learning system is surrounded by an information environment with which they interact. An analogue of the thermodynamic force in a natural tree system is the proposal to study a certain training material (for example, a branch) in the training system (in the “Learning Tree”). This suggestion can be expressed as a negative gradient of the difference between the knowledge potentials of the teacher and the student. An analogue of thermodynamic force in the information environment is the requirement that certain information be taught to the student. This requirement can also be expressed as a negative gradient of the difference between the information environment and the student’s knowledge potential. The training system interacts with the information environment. Therefore, supply may coincide with demand. In terms of physics, the force within the learning system can be balanced by the force within the information environment. It is the processes of bringing supply and demand together that are responsible for the evolution of the training system. These processes do not preclude a deeper, broader explanation of any issue during training.

Figure 1. Learning Tree

Source: Search data.
The need to study the training material related to a certain stage in the proposed training system also makes it necessary to study the materials related to the elements of the stage. This is analogous to the formation of a new leaf from a branch and shows the variability of the training system. These changes are not accidental, but occur in accordance with the requirements of the information environment. This is called adaptation.

Inheritance is clear in the system of teaching Physics with a unified approach. Each subsequent stage of training is based on the previous stage and is its successor. For example, in order to study intensive properties, it is necessary to study extensive properties before it. Let us explain in other words. Suppose that one of the training stages is over. This means that supply at that stage is balanced by demand. This balance can be maintained until the end of the training period. It can be the basis for learning the next steps. This is called inheritance. Thus, the learning process we propose takes place in accordance with natural processes.

**SYNERGETICS OF THE SYSTEM OF TEACHING PHYSICS WITH A UNIFIED APPROACH**

The synergetic features of the system include its being complex, open, unbalanced, non-linear, and self-organized.

The system we propose is complex. This training system includes the training of many different interrelated issues. The training system involves the study of Physics in its entirety on the basis of the stages included in the system and the relationship of the elements within the stage. This is an indicator of synergy. For clarity, we also work in statistical physics with complex systems composed of many subsystems (atoms, molecules). However, the main difference between static physics and the synergetic approach is that statistical physics systems study them on the basis of the properties of the elements that make them up, and synergetics studies them on the basis of inter-element relationships.

The training system we have developed is not based on the principle of superposition, but rather on the principle of interference. This is evident in the evolution of the tree. As the branches of the tree grow, the trunk thickens. As the stages of the training system pass, the quality of the knowledge gained about the forms of movement (body) increases. The fact that the system is not organized on the principle of superposition shows that it is nonlinear.

The training system has a unified approach. The system can receive new scientific information. The need to enter new information changes the requirement. For the evolution of the system, the supply must be balanced with the demand. For balancing, the system changes according to the proposal. There is a need to build a new stage (branch) or intra-stage element (leaf) in the system. The emergence of new legitimate degrees of freedom in the system as a result of the influence of new forces in the environment is called bifurcation. Therefore, the introduction of a new stage, an element in the training system is bifurcation.

The new stage (branch) and the new element (leaf) that accompany bifurcation can "live" for a long time balancing with the environment. The emergence and "survival" of a new stage and element means the ability of the system to self-organize.

We mentioned above that the training system has a hierarchical structure. In other words, the training system provides for the implementation of the necessary (agreed) sequence of training steps that are fully interconnected. This is very close to Haken’s definition of synergetics (HAKEN, 1978).

The evolution of the training system seems to have evolved from "chaos." Materials related to the content of Physics, where the training system has not been established, are in the form of "chaos". There is a stage in the evolution of the training system, the supply of which is balanced by the requirements of the information environment. The emergence and "survival" of the stage means the emergence of order from "chaos". This is in line with Prigogine’s explanation (PRIGOGINE; SIENGERS, 1984).
THE SYSTEM OF TEACHING WITH A UNIFIED APPROACH TO PHYSICS AS A LEARNING TECHNOLOGY

Let us find out whether the presented methodological system meets the criteria of learning technology. The teaching of Physics with a Unified Approach is a process. V.Y. Vilensky’s textbook shows that technology is perceived as a process and is characterized by the following three features (VILENSKY; OBRAZTSOV; UMAN, 2004):

- separation of the process into interrelated stages;
- gradual implementation of actions aimed at obtaining the desired result (achievement of the set goal);
- unambiguous execution of operations included in the technology; this is an important, decisive condition for achieving results that are adequate to the goal.

Selevko Q.K. (2000) studied a large number of learning technologies and defined the criteria for the pedagogical process to be a pedagogical technology. These include: system (complexity, completeness), scientific (conceptual, creative nature), structural (hierarchy and succession, logic, etc.), management (diagnostics, forecasting, efficiency, optimality, repetition) (SELEVKO, 2000). It has been explained above that the pedagogical process - the learning process - meets the criteria of having a systematic, structured criteria. In the presented system, there is an algorithm - the division into separate content areas that occur in a certain order. Depending on the conditions of the technology, it is possible to change the sequence and period of the elements of the algorithm. For example, changing the order of the elements in stages X and XI does not change the result.

Science in the system is explained by the fact that it is based on scientific theories such as classical physics and thermodynamics, thermokinetics, energy dynamics, and modern practical achievements. The efficiency and optimality of the training system is reflected in theization of important concepts - process, force, ordered work, disordered work, etc. for the considered forms of motion. These indicate that the process meets the management criteria. It is clear from our review that the training process we present meets the requirements of being a system, as well as the criteria of learning technology. Our conclusion is that our system of teaching Physics with a Unified Approach can be implemented as the form of learning technology.

CONCLUSION

A system of teaching Physics with a Unified Approach in technical universities has been developed. The system consists of training stages and intra-stage elements and meets the system criteria. There are analogies between the elements of the ideal system and the elements of natural tree. Therefore, the training system is designed in the form of a tree. An analogy of the evolution of this tree and natural tree has been identified. Synergetics was determined by showing that the training system is an open, unbalanced, non-linear, multivariate, self-organizing system. It was proposed to implement the developed training system as a training technology.

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Ways to overcome difficulties in learning physics

Formas de superar dificuldades na aprendizagem da física

Formas de superar las dificultades en el aprendizaje de la física

Resumo
Foi criado um sistema de ensino de Física com abordagem unificada, e explicou-se a metodologia de criação desse sistema pedagógico. Estabeleceu-se uma analogia entre os elementos do sistema e os da árvore, daí porque o processo de aprendizagem foi construído na forma de uma árvore (“Árvore de Aprendizagem”). Os sinérgios do sistema de aprendizagem desenvolvido foram mostrados; foi determinado que ele atendeu adequadamente aos critérios de aprendizagem da tecnologia.

Palavras-chave: Sistema de aprendizagem. Abordagem unificada. Evolução. Sinergias. Tecnologia de aprendizagem.

Abstract
A system of teaching Physics with a unified approach has been created, and the creation methodology of this pedagogical system was explained. An analogy was established between the elements of the system and those of the tree, hence why the learning process was constructed in the form of a tree (“Learning Tree”). The synergetics of the developed learning system was shown; it was determined that it adequately met the criteria of learning technology.

Keywords: Learning system. Unified approach. Evolution. Synergetics. Learning technology.

Resumen
Se ha creado un sistema de enseñanza de la Física con un enfoque unificado, y se ha explicado la metodología de creación de este sistema pedagógico. Se estableció una analogía entre los elementos del sistema y los del árbol, de ahí que el proceso de aprendizaje se construyera en forma de árbol (“Árbol de Aprendizaje”). Se mostró la sinergética del sistema de aprendizaje desarrollado; se determinó que cumplía adecuadamente los criterios de la tecnología de aprendizaje.

Palabras-clave: Sistema de aprendizaje. Enfoque unificado. Evolución. Sinergética. Tecnología de aprendizaje.