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METHODICAL FEATURES OF IMPLEMENTATION OF THE RELATIONSHIP BETWEEN SYMMETRY AND ASYMMETRY BASED ON STEM EDUCATION

Abstract. *The authors analyze the concept of symmetry and asymmetry in the process of teaching physics in technical institutions of higher education. The relationship between symmetry and asymmetry in the process of teaching physics based on STEM technologies is revealed. The use of fundamental ideas of physics (for example, symmetry and asymmetry) taking into account STEM technologies is highlighted. The interrelation of symmetry and conservation laws about their fundamentality is clarified; the technique of the integrated approach of physics and disciplines of the professionally-oriented profile, on an example of studying cosmetic loadings, is presented. It was found that the formation of independent cognitive-exploratory activities of students should use physics problems with consideration of fundamental concepts, such as symmetry caused by the development of motives, cognitive interest and scientific thinking and the acquisition of professional competencies. The demonstration of engineering and technical component of STEM education and development of methods of studying disciplines taught to students of technical institutions of higher education, taking into account the integrated approach and interdisciplinary links, is relevant. The transition to STEM training requires improving the methodology of teaching physics in terms of integrated, systematic, professionally-oriented approaches, which includes: the use of new methods, techniques, teaching aids that would help solve several methodological problems; application and introduction in the educational process of physics of interesting and important scientific achievements, as well as strengthening those aspects that stimulate and intensify the independent cognitive activity of students of technical institutions of higher education. It is established that to improve the quality of teaching physics in future technical specialists it is necessary to systematically improve the methodology of educational and cognitive activities, and more widely apply STEM-learning technologies, which leads to productive mental and practical activities of students in the process of mastering educational material. In the future, work on the study of this problem can be carried out in the following areas: development of a new approach to changing the structure and content of working curricula, improving the content and system of teaching physics taking into account STEM technologies, strengthening the connection between the teaching of physics course and the professional orientation of students of non-physical specialities of technical universities in the context of STEM education.*

Keywords: *physics, STEM technologies, symmetry, asymmetry, methodical features of teaching.*

Problem statement in general and its connection with important scientific or practical tasks. Innovative trends in the development of educational innovations and conceptual principles of the Industrial Revolution 5.0., which are important for the development of cyber-physics systems [1], influence the introduction of innovative technologies (STEM-education, 3D-modelling, elements of artificial intelligence, etc.) in the educational process technical education (speciality 272 "Aviation transport").

An important issue in the implementation of innovative STEM technologies is to ensure a high level of scientific, engineering and technical education in higher education, which meets the capabilities of technological implementation of scientific achievements in physics and technical disciplines, mastering methods of modelling physical phenomena and developing appropriate technological processes. technical direction (http://www.glau.kr.ua/index.php/ua/17-ukrainian/2466–2021). Therefore, one of the directions of reforming physics education in technical education is to strengthen its methodological focus in the development of STEM education (on the example of the relationship between symmetry and asymmetry).

Scientific and innovative activity of applicants for higher education based on the introduction of STEM technologies is due to 1) the development of innovative technologies and the transfer of STEM technologies; 2) change in the methodology of teaching physics and technical disciplines in the HEI of technical direction (the use of artificial intelligence technologies, blockchain, Internet of Things and Industrial Internet of Things, 3D printing, etc.); 3) the need to restore Ukraine's economy after the military crisis, so STEM-innovation is an effective means of achieving this goal.

Therefore, according to the Law of Ukraine "On Scientific and Scientific-Technical Activity" (https://zakon.rada.gov.ua/laws/show/848–19#top), the Law of Ukraine on "Education" (https://zakon.rada.gov.ua/laws/show/2145–19#Text) and "Higher Education" (https://zakon.rada.gov.ua/laws/show/1556–18#Text), it is provided that the main direction updating the content of higher education is to ensure its quality based on the latest advances in science, culture and social practice. Thus, the educational field of "technology" performs the functions of technical and technological education, based on the laws and patterns of man, nature, society, culture and production, studied by subjects of basic sciences.

Physics plays a leading role in the system of natural and technical sciences, as it plays a fundamental role in the development of the productive forces of society. The modern educational process of studying the general course of physics is based on an experimental basis and combined with a theoretical method based on STEM technologies. In this case, regardless of the method of cognition underlying the process of teaching physics, the educational physics experiment is a mandatory element and at the same time an integral part of the methodology of teaching physics based on STEM technologies as a scientific discipline capable of effective learning.

The use of STEM technologies, as one of the means of innovative activity, requires the improvement of methods of teaching physics, which includes: the use of new methods, techniques, teaching aids that would help solve a number of methodological problems in physics; application and introduction of interesting and important scientific achievements in the educational process in physics, as well as strengthening those aspects that stimulate and intensify the independent cognitive activity of students of the Flight Academy of the National Aviation University.

Therefore, in order to form convincing ideas from the course of general physics, it is necessary to create and develop appropriate methods of teaching it (highlighting the concepts of symmetry and asymmetry for the applied aspect of technical disciplines), which would improve STEM competencies and stimulate cadets/students to active cognitive exploratory and independent work in teaching physics. This is achieved with the help of STEM equipment (STEM-kits, research STEM-laboratories, STEM-centers, etc.), which should be implemented in the educational process of free technical education.

An analysis of recent research and publications that have begun to address this issue. In order to develop STEM learning and motivate subjects to research activities in the process of teaching physics and technical disciplines, teachers need to use in their research the work of leading scientists: I. Slipukhina, [2; 3], O. Strizhak [3], I. Chernetskyi, M. Sadovyi, N. Podopryhora, P. Atamanchuk, S. Dembitska, I. Savchenko, N. Goncharova and V. Sipiyi and others.

Definitions of symmetry and asymmetry were considered in the works of B. Gott [4], F. Zemlyanskyi; theoretical aspects of symmetry are outlined in the study of R. Ganiev [5]; string theory, the principles of symmetry were outlined in his works by B. Green [6]; methods of teaching symmetry in general secondary education were developed by I. Kovalev [7], symmetry in classical mechanics was studied by V. Multanovskyi [8]; geometric transformations of symmetry were outlined in his research by M. Murach [9]; leading scientist M. Sadovyi substantiated the methodology of teaching physics on the basis of considering the symmetry of microparticles [10].

In aerodynamics and flight dynamics, scientists Wang Lixin, Xu Zijian, Yue Ting [11] point out that inclined wings significantly change the moment of lifting, resistance and tilt, as well as generate lateral force, moment of rolling and roaring, which are not present in symmetrical wings. Thus to cut asymmetric aerodynamic moments, three-axis control surfaces should deviate in harmony, which balances asymmetric moments. At the same time, the OWA must roll at an angle to balance lateral force [11, pp. 1664–1672].

Well-known scientists Ribe N. M, Brun P-T, Audoly B. [12], considered the structure and principle of operation of a liquid mechanical machine, and the phenomena of symmetry and asymmetry, which are important in the process of its work.

The aim of the article is to substantiate the methodological features of the relationship between the concept of symmetry and asymmetry on the basis of STEM education and the disclosure of experimental testing of teaching methods of physical and technical disciplines of these definitions in technical higher educational institution (HEI).

Methods and techniques. Diagnostic research methods were used in the work: application of research on teaching physics and technical disciplines on the basis of STEM technologies and establishing their influence on the formation of STEM skills in students in the process of teaching physical and technical disciplines.

Symmetry is a category that means the unity of conservation and change, invariance and transformation between different and opposite states of world phenomena [13].

Asymmetry is a category that means the existence and formation in certain conditions of differences and opposites within the unity, identity, and integrity of the phenomena of reality [13].

Dardashti R., Frisch M. and Valente G. [14, pp. 983–989] studied the historical aspects of the concept of symmetry and its principles. These scientists focused on examples of the application of the principles of symmetry (subatomic theories and space-time theories); issues of ontological and epistemological nature concerning the consideration of symmetry and asymmetry in the teaching of physics are revealed.

Studying the symmetry of physics and technical systems, “behaviour in different physics transformations is studied, so if a particle moves rectilinearly in a field with potential $\upsilon(x)$, this potential has mirror symmetry concerning the origin, which satisfies equality $\upsilon(x) = -\upsilon(x)$. In this aspect, the potential is invariant concerning the conversion of the quantity x on $-x$. When a particle moves in three dimensions, we can write the expression in spherical polar coordinates: $\upsilon(r)$. This potential is invariant for any transformation, which consists in rotating to an arbitrary angle around an arbitrary axis passing through the origin” [15, p. 12]. The mathematical apparatus used by scientists in the process of studying the properties of symmetry is called group theory [16; p. 104].

The use of group theory in the study of mixed particles was revealed in his works by Abraham A. Ungar [17], who, based on Lorentz transformations, outlined the definition of symmetry, which is the basis of Einstein’s theory of relativity.

Consider the consequences of the existence of symmetry in quantum mechanical systems, which are important for the mastery of theoretical and practical material by graduates of the speciality 272 “Aviation transport”: 1) conservation laws; 2) transformation of functions in the study of the symmetry operation and the existence for them of asymmetric index independent of the particular form of the Hamiltonian; 3) selection rules; 4) the relationship between the matrix elements of the observed quantities [15, p. 19].

The principle of superposition, considered in quantum theories of symmetry, determines the structure of the extended set of states, and this principle allows to describe these states [17, p. 14]. The principles of symmetry and asymmetry are used in unifying physics theories.

Unifying theories in modern physics can be seen as the formation of a new paradigm in science and technology, the desire to build a single physics picture of the world, the foundation is a synthesis of relativistic and quantum ideas, the idea of building a single theory of all fundamental interactions [18, p. 8; 19]. Modern superstring theory, which claims to be the unifying theory of all four fundamental interactions, is based on the model of supersymmetry.

Scientists S. Illarionov and O. Mamchur outlined the functions of the principles of symmetry in physics cognition [17]: 1) organizing function; 2) restrictive function, which has important aspects of epistemological and ontological nature; 3) unifying function, indicates that "the principles of symmetry play the role of one of the foundations of the tendency of physical knowledge to unity" [17, p. 177].

The task of finding the unity of symmetry and asymmetry in physics and technical phenomena is to impose such operations, which reveal both identities in different and different in identical. Before the symmetry of protons and neutrons concerning strong interactions was established, the difference between them was established, their certain asymmetry for electromagnetic interactions. Particles and antiparticles are asymmetric because in the opposition between them there are identical moments, due to which they are a mirror image of each other. So the unity of symmetry and asymmetry is that they precede each other and are most clearly manifested in the development of our knowledge. Already directly from the definitions of symmetry and asymmetry, we can see that they are based on such general categories as identity, difference, change, formation, ie on such categories that have general significance.

Considering with students the laws of Newtonian mechanics, we note that they are asymmetric concerning Lorentz transformations. The law of entropy growth is asymmetric for the transitions of different types of energy, which establishes the predominant tendency to convert all types of energy into heat.

The presence of asymmetry in the laws does not destroy their content and the existence of symmetry. It, like symmetry, is the basis of the relationship between laws. For example, the asymmetry of the content of the law of entropy growth is the basis on which the connection of this law with the law of conservation and conversion of energy, which is expressed through the existence of such physics quantities as thermodynamic potentials. It is known that the laws of conservation of energy and momentum contain mutual asymmetry: energy is a scalar quantity, momentum is a vector quantity, but there is a deep connection between them, revealed by relativistic theory.

We distinguish and consider the following forms of symmetry and asymmetry: *geometric* and *dynamic*. It should be noted that E. Wigner proposes in his works the third form of symmetry — *cross-symmetry* [16]. The classification of types of symmetry is the classification of types of asymmetry.

Symmetries that express the properties of space and time are referred to as geometric forms of symmetry. Examples of geometric symmetries are homogeneity of space and time, isotropy of space, spatial parity, and equivalence of inertial reference frames.

Symmetries that are not directly related to the properties of space and time and that express the properties of physical interactions are referred to as a dynamic form of symmetry. Examples of dynamic symmetries are the symmetries of electric charge, spin, isotopic spin, and others. Dynamic symmetries include symmetries of internal properties of objects and processes. So geometric and dynamic symmetries can be considered internal and external symmetries. Forms of symmetry are also forms of asymmetry. The asymmetry of the properties of space and time belongs to the geometric, and the asymmetry of the properties of interaction, causality and development — to the dynamic.

Asymmetries, such as the homogeneity of space and time, the anisotropy of space are geometric asymmetries; respectively, the difference between protons and neutrons in electromagnetic interactions, the differences between particles and antiparticles in electric, baryon, lepton charge — dynamic asymmetries.

There is an inextricable link between geometric and dynamic forms of asymmetry. We will show students this connection by the following example: the asymmetry of space — Riemann's time is a consequence of the presence of strong gravitational fields or equally large masses of matter.

Note that the law of conservation of energy cannot be unambiguously associated with such symmetry as the homogeneity of time, and the law of conservation of momentum — with the homogeneity of space. There is, of course, a significant connection between these symmetries and the laws of conservation, but it cannot be considered unambiguous in the sense that these symmetries determine the whole meaning of these laws of conservation. It should be noted that the content of each law of conservation includes symmetry, as well as asymmetry.

The law of conservation and conversion of energy includes the asymmetry of direct and indirect methods of energy conversion, which is that indirect methods of conversion through heat prevail over direct methods of conversion of any form of energy into any other form. The law of conservation of momentum in classical mechanics is asymmetric concerning Lorentz transformations.

The asymmetry inherent in this law is expressed in the fact that when calculating the final transmission rate of the interaction, the equality of action and counteraction is violated. Extensive study of conservation laws requires the disclosure in their content of both moments of symmetry and asymmetry. From the above it follows that attempts to derive conservation laws only from certain forms of symmetry (the law of conservation of energy — from the homogeneity of time, the law of conservation of momentum — from the homogeneity of space) is possible only with a unilateral interpretation of these laws, so they can not be entirely correct.

If we consider the well-known theorem of E. Noether, it does not derive, for example, the law of conservation of energy from the homogeneity of time, but only reveals the relationship of some of its forms with this form of time symmetry, which, of course, is important.

Derivation of conservation laws only from geometric symmetry is impossible. Conservation laws are related not only to geometric symmetries but also to dynamic ones. This connection, for example, is clearly stated in the law of conservation of the total momentum of electrons in atoms, which refers to their spin and spin-orbit interactions. In the latter, as is known, the internal degrees of freedom of electrons, ie, dynamic symmetries are associated with their motion in space, and hence with geometric symmetries.

Therefore, recognizing the importance of this aspect in the analysis and theoretical justification of conservation laws, it should be noted its limitations.

There is undoubtedly a connection between symmetry, asymmetry, and conservation laws, but the whole content of conservation laws is reduced to forms of symmetry and asymmetry. The task of theoretical substantiation of conservation laws is not only to reveal their connections with forms of symmetry and asymmetry, but also to reveal their connections with each other, with the structure of fields, with such general laws as the law of conservation of matter and motion and the law of unity of matter.

The existence of the preservation of laws, as a rule, is due to the presence in this system of a symmetry. For example, the homogeneity of time preserves the laws of energy, and the homogeneity of space preserves the laws of momentum. However, the concept of symmetry can be extended to include abstract concepts not related to geometry. For example, one of the symmetries is related to the work done when lifting the body.

The energy expended depends on the height difference that needs to be overcome. But energy does not depend on absolute altitude: it does not matter whether altitudes are measured from sea level or land level — only the difference in altitude is important. This is an illustration of what physicists call calibration symmetries associated with changes in scale.

These descriptions of different types of symmetry give us enough reason to talk about the huge role of the principle of symmetry in modern physics. This role of symmetry requires the expediency of its definition.

The law of conservation of momentum is a consequence of translational invariance of space (homogeneity of space). If the Lagrange function remains unchanged at any infinitesimal transfer of a closed system in space, we obtain the law of conservation of momentum.

In classical mechanics, the law of conservation of momentum is usually derived as a consequence of Newton's laws. From Newton's laws we can show that when the system moves in space, the momentum is preserved in time, and in the presence of external influence, the rate of change of momentum is determined by the sum of applied forces.

Consider the derivation of Newton's law in dynamics. According to Newton's second law, for a system of *N* particles the relation is fulfilled

$$\frac{d\vec{p}}{dt} = \vec{F}\,, \qquad (1)$$

where $\vec{p}$ — the momentum of the system $\vec{p} = \sum_{i=1}^{N} \overrightarrow{p_n}$, $\vec{F}$ — is equal to all the forces applied to system particles $\vec{F} = \sum_{k=1}^{N} \overrightarrow{F_k^{ext}} + \sum_{n=1}^{N}\sum_{m=1}^{N} \overrightarrow{F_{n,m}},\ m \neq n\,.$ (2)

$\overrightarrow{F_{n,m}}$ — force acting on *n* a particle from the side *m*; F_k^{ext} — is equal to all external forces applied to the k-th particle.

According to Newton's third law, forces $\overrightarrow{F_{n,m}}$ and $\overrightarrow{F_{m,n}}$ levels are absolute in value and opposite in direction, ie $\overrightarrow{F_{n,m}} = -\overrightarrow{F_{m,n}}$. Therefore, the second sum in the right part $\vec{F} = \sum_{k=1}^{N} \overrightarrow{F_k^{ext}} + \sum_{n=1}^{N}\sum_{m=1}^{N} \overrightarrow{F_{n,m}},\ m \neq n$

of the expression will be zero, the internal forces are excluded, and the derivative of the momentum of the system over time is equal to the vector sum of all external forces acting on the system:

$$\frac{d\overline{p}}{dt} = \sum_{k=1}^{N} \overline{F_k^{ext}} \,. \qquad (3)$$

For a system of *N* particles, in which the sum of all external forces is zero:

$$\sum_{k=1}^{N} \overrightarrow{F_k^{ext}} = 0 \,, \qquad (4)$$

especially for a system whose particles are not affected by external forces (for all *k* from 1 to *N*), we have

$$\frac{d}{dt}\sum_{n=1}^{N} \overline{p_n} = 0 \,. \qquad (5)$$

The derivative of the expression is zero, ie there is a constant value for the variable differentiation, which means:

$$\sum_{n=1}^{N} \overrightarrow{p_n} = const \,. \qquad (6)$$

That is, the total momentum of a system of *N* particles is a constant value. At *N* = 1 we obtain the expression for the case of one particle. Thus, the conclusion arises [18]:

If the vector sum of all external forces acting on the system is zero, then the momentum of the system is preserved, ie does not change over time.

The law of conservation of momentum is fulfilled not only for systems that are not affected by external forces, it is also valid in cases where the sum of all external forces acting on the system is zero.

If the projection of the sum of external forces on any direction or coordinate axis is zero, then in this case we are talking about the law of conservation of the projection of the pulse in this direction or coordinate axis. As a result of the research and the above, we state that the expediency of subordinating the content of educational material in physics is based on fundamental concepts, one of which is symmetry and asymmetry.

Accordingly, the acquaintance and study of these concepts by students will contribute to the formation of modern scientific thinking, as well as provide systematization of knowledge in physics and the formation of the scientific worldview.

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However, the concept of symmetry can be extended to include abstract concepts not related to geometry. For example, one of the symmetries is related to the work done when lifting the body. The energy expended depends on the height difference that needs to be overcome. But energy does not depend on absolute altitude: it does not matter whether altitudes are measured from sea level or land level — only the difference in altitude is important. This is an illustration of what physicists call calibration symmetries associated with changes in scale.

Consider, as an example of the use of the fundamental physical concept of symmetry in the teaching of students in the disciplines of physics, theoretical mechanics and resistance of materials in higher education institutions of the technical profile, given the transdiplinar approach to learning.

Oblique load. Consider a statically indeterminate frame (*Fig. 1, a*) under the action of obliquely asymmetric loading (*Fig. 1, b*). For its calculation we use the main system and the main unknowns (*Fig. 1, c*).

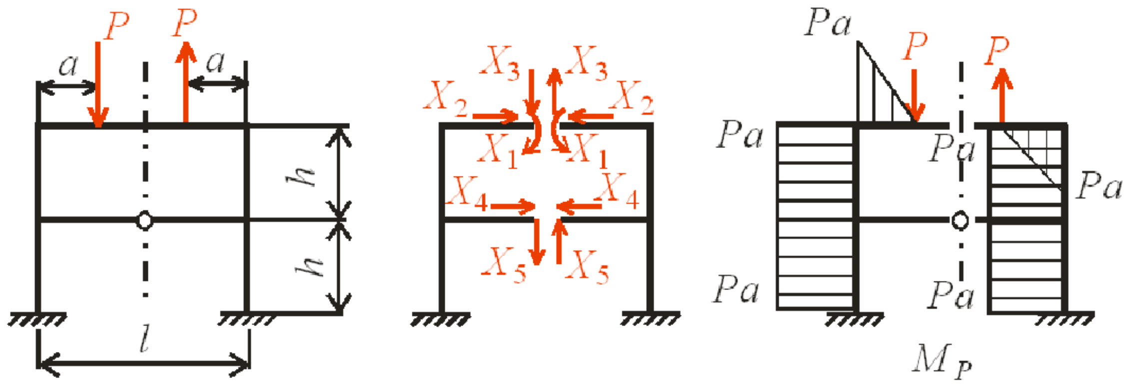
The first subsystem, which contains unknown only symmetric forces, due to the oblique symmetry of the plot of the moments of the cargo state (*Fig. 1*) will have zero free members:

$$\begin{aligned} \delta_{11}X_1 + \delta_{12}X_2 + \delta_{14}X_4 &= 0; \\ \delta_{12}X_1 + \delta_{22}X_2 + \delta_{24}X_4 &= 0; \\ \delta_{14}X_1 + \delta_{42}X_2 + \delta_{24}X_4 &= 0. \end{aligned} \qquad (7)$$

This homogeneous system of equations has a trivial solution, ie $X_1 = X_2 = X_4 = 0$. Thus, the basic skew-symmetric unknowns can be determined by solving the second subsystem of equations:

$$\begin{aligned} \delta_{35}X_3 + \delta_{53}X_5 + \Delta_{3p} &= 0; \\ \delta_{35}X_3 + \delta_{55}X_5 + \Delta_{5p} &= 0. \end{aligned} \qquad (8)$$

Therefore, in a symmetrical frame under the action of obliquely symmetrical loading, the unknowns are equal to zero. It is necessary to define only obliquely symmetric basic unknowns. Valid plots $M_{ä}$ and $N_{ä}$ will be obliquely symmetrical, and the plot $Q_{ä}$ — symmetrical.



a) b) c)

Fig.1. Statistically indeterminate frame

Conclusions and prospects for further explorations in this direction. Thus, methodological principles play an important role in scientific knowledge. They perform a methodological function in the growth of scientific knowledge. The principle of symmetry as a methodological principle crystallized in scientific theory and acquired the status of "general methodological" because its internal content and methodological functions are so abstract that they become common to science. Among other factors, a huge role in this was played by the fact that the very abstract form of representation of the term "symmetry" and its semantic meaning allows its use in a wide range of scientific knowledge.

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МЕТОДИЧНІ ОСОБЛИВОСТІ РЕАЛІЗАЦІЇ ВЗАЄМОЗВ'ЯЗКУ СИМЕТРІЇ ТА АСИМЕТРІЇ НА ЗАСАДАХ STEM-ОСВІТИ

Анотація. *У статті проаналізовано поняття симетрії та асиметрії у процесі навчання фізики в технічних закладах вищої освіти. Розкрито взаємозв'язок симетрії та асиметрії в процесі навчання фізики на основі STEM-технологій. Висвітлено використання фундаментальних ідей фізики (на прикладі симетрії та асиметрії) з урахуванням STEM-технологій. З'ясовано взаємозв'язок симетрії та законів збереження щодо їх фундаментальності; представлена методика інтегрованого підходу фізики та дисциплін професійно орієнтованого профілю на прикладі вивчення косометричних навантажень. З'ясовано, що, формуючи самостійну пізнавально-пошукову діяльність здобувачів освіти, потрібно використовувати фізичні задачі з розглядом фундаментальних понять, наприклад симетрії, що викликано розвитком мотивів, пізнавального інтересу та природничо-наукового мислення і набуттям професійних компетентностей. Актуальним постає показ інженерної і технічної складової STEM-освіти та розроблення методики вивчення дисциплін, які викладаються студентам технічних закладів вищої освіти з урахуванням інтегрованого підходу та міждисциплінарних зв'язків. Перехід на STEM-навчання вимагає удосконалення методики навчання фізики в умовах інтегрованого, системного, професійно орієнтованого підходів, що передбачає: використання нових методів, прийомів, засобів навчання, які допомагали б вирішити низку методичних завдань; застосування і запровадження в освітньому процесі з фізики цікавих і важливих наукових досягнень, а також посилення тих аспектів, які стимулюють та активізують самостійну пізнавальну діяльність студентів технічних закладів вищої освіти. Визначено, що для підвищення якості навчання фізики у майбутніх фахівців технічного профілю необхідно систематично вдосконалювати методику організації навчально-пізнавальної діяльності, ширше застосовувати STEM-технології навчання, що приводить до продуктивної розумової і практичної діяльності студентів у процесі опанування навчальним матеріалом, а це має прикладний аспект. Надалі робота з дослідження цієї проблеми може проводитися у таких напрямах: розроблення нового підходу до зміни структури і змісту робочих навчальних програм, удосконалення змісту й системи навчання фізики з урахуванням STEM-технологій, підсилення зв'язку викладання курсу фізики з фаховою спрямованістю студентів нефізичних спеціальностей технічних університетів у контексті STEM-освіти.*

***Ключові слова**: фізика, STEM-технології, симетрія, асиметрія, методичні особливості навчання.*

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