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STRUCTURAL-FUNCTIONAL MODEL OF TEACHING PHYSICAL AND TECHNICAL DISCIPLINES BASED ON STEM EDUCATION: THE ASPECT OF TRANSDISCIPLINARITY

Abstract. *The development of innovativeness affects the modernization of higher education, in particular, technical in the context of STEM education. It was noted that the modernization of higher education in Ukraine needs to take into account the general trends in the development of higher education systems in the context of globalization and European integration processes. The expediency of the structural-functional model of teaching physical and technical disciplines on the basis of STEM education in the conditions of transdisciplinarity is substantiated. It has been established that a change in the field of higher education, in particular technical, taking into account the development of STEM education, involves a review of the concept of training specialists in each specific field of activity, therefore, the modernization of the content of education requires updating the educational and methodological base (goals, content, methods, forms and means), through which modern innovative approaches will be implemented in the future. The experimental component of the study of physical phenomena has developed due to an increase in the number of different types of experiments (quantitative and qualitative) in physical experiments using STEM technologies (new physical kits, ICT, 3-D modeling, etc.). Taking into account modern trends and the main directions of improvement of the educational process, a methodology for teaching physical and technical disciplines was created, which is aimed at effectively familiarizing students with the basics of physics, which is necessary for further study of the disciplines of a professional direction and should be aimed not only at high-quality, scientifically and methodologically justified teaching of the content of its basics, which is provided by the educational activity of the teacher but also mainly at the activation of independent educational and research activities of students. Such a method should develop and stimulate interest in knowledge and understanding of Physics, their application in explaining the phenomena and processes of the microcosm and the surrounding world as a whole, and give students an effective system of knowledge, skills and abilities, and form a scientific outlook. The results of the conducted comparative experiment to identify the effectiveness of the proposed method of teaching physical and technical disciplines in the context of STEM education showed that the level of formation of physical knowledge, abilities and skills of students of higher education in the control groups is lower than the corresponding level in the experimental groups. The critical value determined according to the table* χ^2 *for the level of significance accepted in pedagogical research is* $\alpha = 0,05$*;* $\chi^2_{crit.} = 12,59$*,* $\chi^2_{\exp.} = 13,3$*, that is* $\chi^2_{\exp.} > \chi^2_{crit.}$*, and on the basis of the Kolmogorov-Smirnov criterion leads to the conclusion* $T_{observ.} > W_{1-\alpha}$*, that is (0.035 > 0.0003), that is, the developed method of teaching physical and technical disciplines in the conditions of the development of STEM education is more effective than the existing one.*

Keywords: *transdisciplinarity, STEM education, physical and technical disciplines, structural-functional model, educational process.*

Problem statement in general and its connection with important scientific or practical tasks.

The tasks facing higher education require shifting the emphasis in the educational process from the progressive accumulation of knowledge to the formation of a creative and active personality of the student during education, the formation of industriousness and the development of his individual abilities and talent, the formation of readiness for self-education. These priority directions for the development of physical education in technical institutions of higher education (hereinafter — HEI) are implemented through the improvement of the educational process in physical and technical disciplines, the improvement and development of new teaching aids, technologies (STEM, robot technical kits, elements of virtual and augmented reality, artificial intelligence, etc.).

Analyzing the identified problems through the prism of associative and activity theory of learning [1–2] taking into account the requirements of transdisciplinary, integrated, competence and systemic approaches to the study of educational phenomena and processes, generalization of the pedagogical experience of teachers of Physics and technical disciplines in HEI based on STEM technologies outlined the contradictions that arose between:

- the needs of society for highly qualified specialists who can quickly adapt to the requirements of the modern labor market and the incomplete compliance of the domestic education system with regard to the content of the professional training of specialists in the technical field of study in the context of state requirements for the development of STEM education;
- the traditional methodology of teaching physics in technical HEI and the potential opportunities of the direction in the methodology of teaching Physics, which is based on the means of STEM-education technology;
- introduction of innovative approaches to teaching physical and technical disciplines and their fragmentation in the process of formation of professional competence, which is formed in the conditions of the development of STEM education.

In our opinion, such a task can be implemented to a large extent using implementation of STEM education technologies into the educational process.

This approach to solving the problem meets the requirements of ensuring the competitiveness of Ukrainian higher school graduates among specialists from the countries of the European Union. Under modern conditions, it is important to implement modern technologies, which is provided by the training of specialists in the field of information technologies, mechatronics, automation, etc., in particular, in the process of teaching physical and technical disciplines of technical HEI students based on STEM education technologies [3–5].

The identified contradictions outlined the problem, which consists in the lack of a methodological rationale, a theoretical and methodological basis for the introduction of STEM technologies to the education of technical HEI students; in the lack of formation of the methodology of teaching physical and technical disciplines of technical HEI graduates on the basis of STEM-education technologies.

An analysis of recent research and publications that have begun to solve this issue.

Reforming modern education and updating the methodology of teaching physical and technical disciplines based on STEM technologies is connected with a change in the educational paradigm, which reflects a set of theoretical principles for the entire process of pedagogical activity.

The purpose of the research is to create and justify a structural-functional model of teaching physical and technical disciplines and, based on it, to develop a methodology for teaching physical and technical disciplines to students of technical HEI based on STEM education technologies, which will allow ensuring their active cognitive-searching, independent activity throughout life, while ensuring high availability and quality of education for the training of next-generation specialists.

The concept of the research is determined by the fact that the physical and technical training of future specialists in engineering and technology in technical HEI is the foundation for the further formation of personal and professional qualities of the future competitive specialist in the subjects of training, his ability and readiness for the appropriate type of professional activity, taking into account modern trends in the development of education (digitalization, elements of artificial intelligence, STEM technologies). The concept proposed by the authors of the study is based on the leading idea that the formation and development of STEM soft skills of future specialists in physical and technical disciplines of the technical direction of education is based on the principles of the unity of fundamentalization and transdisciplinary, integrated, competence-based, professionally oriented approaches, which ensures the readiness of subjects of training to solve educational and research tasks in preparation for effective professional activity.

In their research, the authors outlined concepts that reflect the relevance and importance of scientific work:

- the methodological concept reveals the relationship and interaction of certain approaches to solving the problem of the formation and development of STEM soft skills from physical and technical disciplines;
- the theoretical concept defines a system of basic legal provisions, the latest scientific concepts laid as a basis for understanding STEM education in the process of learning physical and technical disciplines; peculiarities of the educational and cognitive activity of education seekers in the conditions of a transdisciplinary approach to the teaching of physical and technical disciplines, taking into account STEM technologies in technical HEI; professional qualifications, key professional STEM competencies;
- the methodical concept involves the development, substantiation and description of the structural-functional model and methodical system of teaching physical and technical disciplines based on STEM technologies in technical HEI, determining the stages of its transdisciplinarity and interdisciplinary integration of implementation in the practice of education.

In accordance with the purpose of the research, *the research tasks were formulated:*

1. To perform an analysis of scientific research and scientific-methodical literature of domestic and foreign researchers designing and forming the main directions of development of theory and practice regarding the creation of a structural-functional model of teaching physical and technical disciplines based on STEM-education and methods of teaching physical-technical disciplines using STEM-education in technical HEI.

2. To investigate the problem of ensuring the effective integration of Physics and technical disciplines in the educational process of technical HEI based on the concept of STEM education.

3. To create and substantiate a model of a structural-functional model of teaching physical and technical disciplines based on STEM education in conditions of transdisciplinarity.

4. To develop and implement methodical support in physical and technical disciplines, taking into account the trends in the development of STEM education for HEI, which will be reflected in the formation of the appropriate professional competence of the students of education.

5. To experimentally verify the effectiveness of the structural-functional model of teaching physical and technical disciplines on the basis of STEM education and the methodology of teaching physical and technical disciplines based on STEM technologies in HEI.

The object of the research is the educational process in physical and technical disciplines in HEI.

The subject is the creation of a structural-functional model of teaching physical and technical disciplines research based on STEM education in the conditions of a transdisciplinary approach.

Research methods: theoretical: analysis of textbooks, methodological manuals and publications reflecting the problem of research in STEM education, to identify modern physical scientific positions and achievements, trends in the development of physical and technical disciplines in higher education; *empirical*: questionnaires, surveys of higher education applicants to find out the level of interest and activity of students / cadets in learning physical and technical disciplines using STEM technologies; *experimental*: pedagogical experiment (declarative, formative) and experimental verification of the effectiveness of the structural-functional model of physical and technical disciplines and methods of teaching physical and technical disciplines using STEM technologies in HEI.

The authors of the research highlighted the *signs of innovations*, which are a significant factor for the creation of a structural-functional model of physical and technical disciplines based on STEM education, which is characterized by the scale in the education system and the innovativeness of their potential: 1) at the macro level, the transformation of innovations takes place, which leads to radical changes and conditions the renewal of the entire system of education in HEI; 2) at the meso level, staffing takes place according to the main directions of interrelated innovations in each component of the education system: preschool, general secondary, extracurricular, professional, higher education, postgraduate; 3) improvement, i. e., modernization, modification, and rationalization of the traditional pedagogical process takes place at the micro level, which determines the locality or singularity of unrelated innovations, i. e., changes that lead to elemental modifications.

The main directions of the state education policy are defined [6]: 1) reform and modernization of the higher education system with EU requirements; 2) activation of the mobility of education seekers, scientific, scientific-pedagogical and pedagogical workers; 3) ensuring availability and continuity of education throughout life; 4) development of scientific and innovative activities in education, improvement of the quality of education on an innovative basis; 5) improvement of information and resource provision of education and science; 6) provision of national monitoring of the education system; 7) creation of a modern material and technical base of the education system.

Based on the identified directions, the updated strategy for reforming the educational sphere requires new scientific research, the well-founded and consistent introduction of modern scientific and pedagogical technologies, and rational and effective approaches to the organization of scientific and innovative activities in education.

I. Chernetskyi and I. Slipukhina point out that physical and mathematical content is fundamental in STEM-oriented physics education. However, its implementation involves, first of all, the use of the engineering method of research (engineering design), which includes such stages as determining the essence of the problem, preliminary research, defining requirements, brainstorming, developing and testing a prototype, evaluating the result, making changes and presenting the obtained result [7, p. 224–225].

Taking into account the modern level of scientific and technical progress increases the importance of the technical component in the training of specialists, which requires: the transfer of the process of teaching physical and technical disciplines of higher education to a higher level, especially with the use of STEM learning technologies to support and organize the educational and cognitive activities of the student of education. The use of STEM technologies as a means of learning in the teaching methodology of physical and technical disciplines with a combination of trans-disciplinary and professionally oriented approaches makes it possible to strengthen the professional orientation of the training of a future technical specialist.

Having analyzed trends in the development of higher education in Ukraine in the context of STEM education from the standpoint of innovation and fundamentality [8–11], the authors singled out:

1) rapid growth of the amount of scientific information, fundamentalization, provides universal, system-forming, invariant knowledge by means of STEM technologies. For this purpose, we propose to form in subjects of education a fundamental core of knowledge and ideas about concepts, phenomena, processes in physical and technical disciplines based on a transdisciplinary approach in accordance with certain topics of professional direction disciplines, which contributes to the formation of STEM soft skills of HEI students;

2) psychophysical features of an education seeker, who is unable to remain in mental stress for a long time due to the need to process a large amount of information, the authors propose to implement through a transdisciplinary approach to teaching physical and technical disciplines based on STEM technologies at the level of interdisciplinary connections, which changes the view on traditional education;

3) transdisciplinarity and fundamental training of a new generation student in Physics is the basis for professional development and mobility in the future. This provides an opportunity on the basis of STEM education for subjects of education to independently adapt to new professional conditions, master modern principles of work, new equipment, technologies and perform professionally significant functions by means of STEM education.

Emphasizing the importance of fundamentalization as a didactic principle for the design of the content of teaching physical and technical disciplines in HEI from the standpoint of the paradigm of STEM education and taking into account the transdisciplinarity and fundamentalization of teaching physical and technical disciplines based on STEM education, relying on the study of the content of teaching Physics by S. Honcharenko [12], the authors have defined the following *conceptual principles of transdisciplinarity of teaching physical and technical disciplines in based on STEM education technologies*:

- STEM-technologies: provide an effective study of the teaching theory of physical and technical disciplines not only at the classical level but also at higher levels, taking into account theoretical generalizations and the use of digital technologies, taking into account didactic requirements for the organization of various types of classes in conditions of transdisciplinarity;

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- definition of the content, provided based on the specifics of the subject field — Physics and technical field — disciplines of an applied nature, according to a common transdisciplinary designation and interdependence of empirical and theoretical knowledge in the context of STEM education;
- the traditional process of forming the concepts of physical and technical disciplines is uniform and linear, STEM technologies ensure the transfer of this process to a non-linear one, where the mathematical level of generalizations is made in parallel with the theoretical one;
- the continuity of content lines and theoretical generalizations of basic STEM-educational educational elements from physical and technical disciplines, takes into account the applied orientation and variability of methods of solving educational and practical tasks, taking into account their transdisciplinarity;
- STEM learning technologies of physical and technical disciplines take into account the unity of psychological-pedagogical and content aspects (abstract-logical, divergent, theoretical and critical types of thinking of education seekers and orientation to the theoretical level of generalization in the development of thinking through analysis, synthesis, comparison, generalization, abstraction, classification, systematization, specification);
- the use of STEM means of education is determined by psychological, pedagogical, organizational and methodical, material and technical, ergonomic conditions, which contributes to the development of research-search and creative activity of education seekers in the process of solving educational and professionally-oriented tasks in the teaching of physical and technical disciplines;
- the creation of adaptive learning systems, which must contain two important components — the creation and maintenance of a modern powerful adaptive hardware and software environment and filling it with pedagogically appropriate and methodically balanced subject content.

Based on this approach, the content of physical and technical disciplines is formed, related to knowledge about the structuring of the subject field, as well as to the strategy of the student's learning trajectories to support flexible personalized learning. At the same time, a holistic learning process is formed, which optimizes the mental development of the student. The psychological and pedagogical means of implementing the educational module is a didactically adapted system of concepts of the subject area in the form of a knowledge system, with the provision of technology for the assimilation of educational content [13].

Based on the established principles, the authors developed a structural and functional model of teaching physical and technical disciplines based on STEM education *(Fig. 1)*.

At the current stage of education, the ability of teachers to teach students to solve problem situations related to practical activities using a transdisciplinary approach to teaching physical and technical disciplines in the context of the development of STEM education is relevant. It is expedient to consider the interdisciplinary relationships of Physics with technical disciplines [14], where subject competencies are formed in students.

Thus, innovative activity and the fundamentalization of physical and technical education in HEI using STEM education is an integral and important component of the professional competence of education seekers. For these reasons, teaching Physics involves the formation of a system of fundamental physical knowledge and skills in students during the study of the disciplines of professional direction and in their life activities. Trends related to innovation, informatization, and computerization have a significant impact on student learning technologies.

Taking into account the developed structural and functional system of teaching physical and technical disciplines based on STEM education is the basis for the development of a methodical system of teaching physical and technical disciplines in the conditions of the development of STEM education, which, in our opinion, should ensure the improvement of the quality of their physical and technical education for further training in the disciplines of the professional direction of study in HEI.

One of the tasks of our research was to check the effectiveness of the created structural-functional model of teaching physical and technical disciplines on the basis of STEM education and the results of introducing the developed methodology of teaching physical and technical disciplines into the practice of teaching HEI, taking into account the trends in the development of STEM education.

In order to ensure the quality of the experiment, when choosing HEI, experimental and control groups, equalization of conditions was

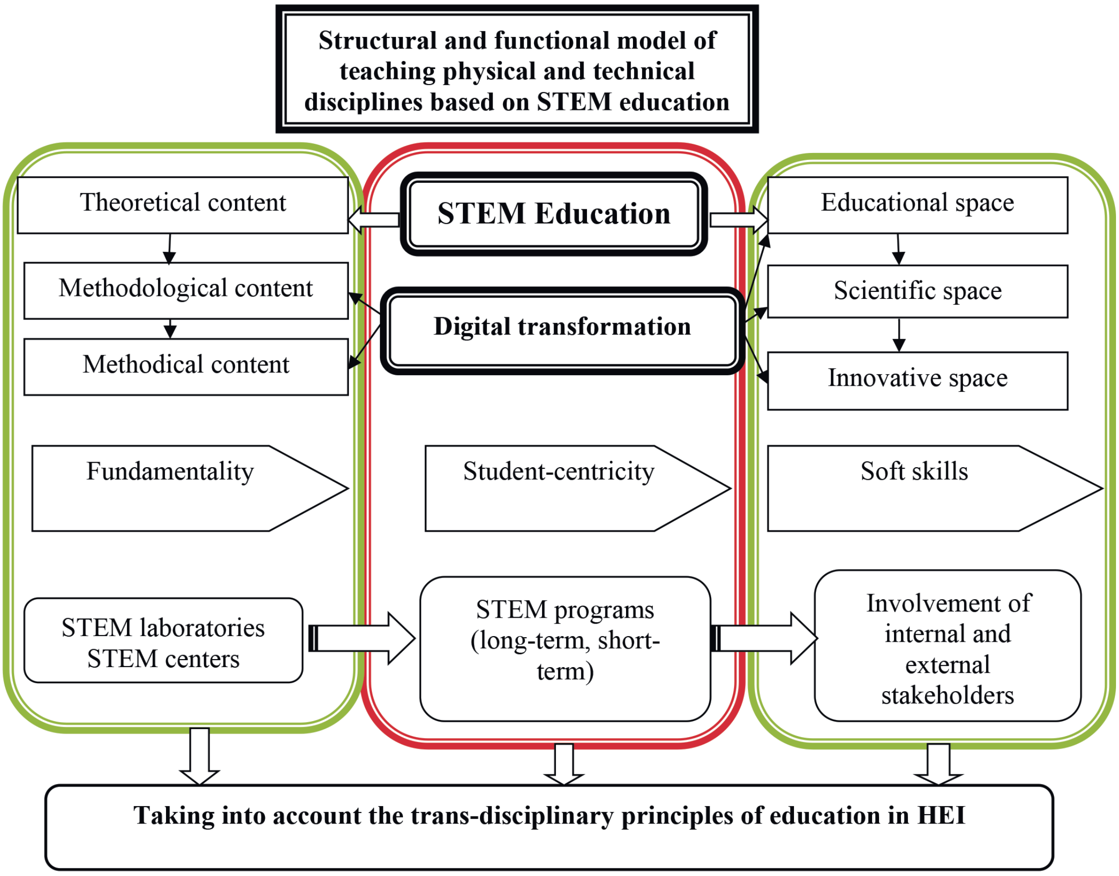

Fig. 1. Structural and functional model of teaching physical and technical disciplines based on STEM education

taken into account, under which the leveling of the difference between the main subjects of the educational process in such groups was assumed: ensuring a relatively equal composition of students in the control and experimental groups. Participation of the involved teacher in the experiment of each type of group.

Study, adjustment and generalization of the effectiveness of the structural-functional model of teaching physical and technical disciplines on the basis of STEM education; the results of approbation of the proposed methodology of practical and experimental tasks by students of physical and technical disciplines based on STEM technologies, were carried out through selective attendance of classes, discussion with teachers of the possibilities of improving the learning process during the training of physical and technical disciplines in experimental groups, analysis of the effectiveness and efficiency of training in the context of the development of STEM education.

The analysis of the results obtained in the course of this pedagogical experiment was aimed at checking the quality and effectiveness of the proposed method of teaching physical and technical disciplines using modern teaching tools taking into account STEM education and comparing the achievements of the students of the experimental and control groups. In each group that participated in the experiment, control work was carried out, as a result of which the level of knowledge, abilities and skills during the proposed methodology of teaching physics was checked, and a comparison was made with those who studied according to the traditional methodology. During the selection of questions for control papers, preference was given to the optimal amount of tasks of different levels, questions, giving answers to which required knowledge and understanding of the essence of observed phenomena during the study of Physics and disciplines of a technical profile and the main regularities of their course: the ability to explain an experimental fact and justify the necessary conditions under which the course of this or that physical phenomenon is possible; to explain

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the methods and ways of managing its main regularities of the course of phenomena and processes, the possibilities of their practical use.

Statistical methods make it possible to establish the probability of certain events in the pedagogical process, to predict learning outcomes, to establish average, critical, and optimal norms and deviations from norms that the pedagogical process in HEI should follow.

In order to statistically process the results of the formative pedagogical experiment, statistical hypothesis testing methods based on the comparison of measurements of some property in two independent samples (criterion χ^2) were used.

The criterion was used to compare the distributions of objects of two populations according to the state of some property. The effectiveness of test works in the physical and technical disciplines of experimental (EG) and control groups (CG), which were implemented in higher education institutions, namely Vinnytsia National Technical University, National Center "Junior Academy of Sciences of Ukraine" was checked.

The samples of education seekers formed in EG and CG are respectively random and independent of each other. The property being measured (the ability to quickly and correctly answer test questions when studying physics sections in a short period of time) has a continuous distribution and is measured on an ordinal scale that has 7 categories.

For the pedagogical experiment, 341 students were selected for the control group (CG) and 353 students for the experimental group (EG), a total of 694 students from Vinnytsia and Kyiv of the HEI took part in the pedagogical experiment.

Table 1 shows the results of points scored when performing physics test tasks in the control and experimental groups.

To identify statistically significant differences in the knowledge levels of students of the control and experimental samples, we use the method of testing the null and alternative hypotheses according to the Pearson test (χ^2) since all the conditions necessary for this are met, i. e.: 1) both samples are random; 2) the samples are independent and the members of each of the samples are independent of each other; 3) the scale of measurements is a scale of names with 7 categories.

The dynamics of changes in the knowledge of education seekers when performing physics test tasks are shown in the diagram *(Fig. 2)*.

Table 1

The results of points scored when performing test tasks in physics in the control (CG) and experimental (EG) groups

Assessment	The number of students who scored a certain number of points			
	Confirmatory experiment		Formative experiment	
	EG	CG	EG	CG
A/90–100/	15	8	18	8
B/80–89/	28	35	45	27
C/75–79/	34	42	64	32
D/60–74/	41	53	39	41
E/50–59/	27	44	31	39
FX/35–49/	2	7	9	5
F/1–34/	0	0	0	0
	147	189	206	152

Let us denote p_{1i} (i = 1, 2, 3, 4, 5, 6, 7) the statistical probability of students of the first sample performing the work for the assessment i; p_{2i} (i = 1, 2, 3, 4, 5, 6, 7) is the statistical probability of students of the second sample performing the work for the assessment i.

Based on the experimental data shown in the above table, we test the null hypothesis: H_0: $p_{1i} = p_2$ for all categories (C = 7).

An alternative hypothesis for H_1: $p_{1i} \neq p_{2i}$ at least one of the mentioned seven categories. We calculate experimental statistics according to the formula:

$$T = \frac{1}{n_1 \cdot n_2} \cdot \sum_{i=1}^{c} \frac{(n_1 \cdot Q_{2i} - n_2 \cdot Q_{1i})^2}{Q_{1i} + Q_{2i}}. \quad (1)$$

According to tabular data α=0,05 and the number of degrees of freedom ν = $C - 1$ = 7 – 1 = 6, we find the critical value of the criterion T statistic: T: $x_{1-\alpha}$ = 12,59, i. e. $T_{critical.}$ = 12.59.

For the control and experimental samples before the experiment, $T_{observ.}$<$T_{critic.}$ (6.98 < 12.59), which is the basis for accepting the null hypothesis.

The control sample before and after the experiment also have statistically significant differences $T_{observ.}$<$T_{critic.}$ (15.822 > 12.59).

The control and experimental samples after the experiment have statistically significant differences, since $T_{observ.}$>$T_{critic.}$ (13.3 > 12.59).

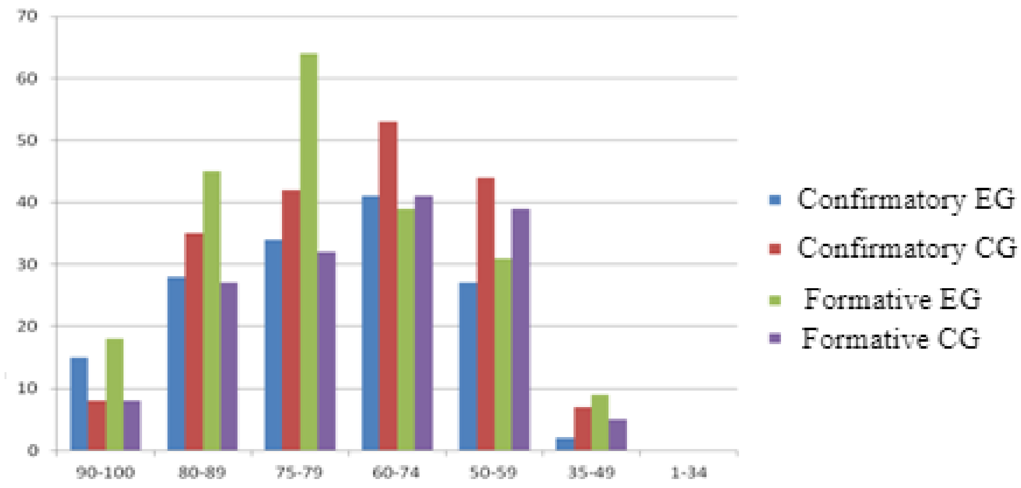

Fig. 2. Comparative characteristics of educational achievements of education seekers when performing test tasks in experimental and control groups in physics based on STEM technologies

The results of experimental statistics calculations are given in Table 2.

In accordance with the decision-making rule, the obtained results allow rejecting the null hypothesis H_0 and accepting the alternative one H_1. So, in this way, it can be concluded that the students of the experimental groups during the performance of physics tasks due to the use of the proposed method of teaching Physics based on STEM technologies showed better results than the students

Table 2

The results of the ascertaining and formative experiment

To the experiment			90–100	80–89	75–79	60–74	60–59	35–49	1–34	$T_{observ.}$
	EG	Q_{1i}	15	28	34	41	27	2	0	
	CG	Q_{2i}	8	35	42	53	44	7	0	
		Q_{2i}-Q_{1i}	-7	7	8	12	17	5	0	
		T	4,3	0,012	0,03	0,0006	0,94	1,7	0	6,98
After the experiment			90–100	80–89	75–79	60–74	60–59	35–49	1–34	$T_{observ.}$
	EG	Q_{1i}	18	45	64	39	31	9	0	
	CG	Q_{2i}	8	27	32	41	39	5	0	
		Q_{2i}-Q_{1i}	-10	-18	-32	2	8	-4	0	
		T	1,45	0,72	3,27	2,53	5,03	0,3	0	13,3
Control group before and after the experiment			90–100	80–89	75–79	60–74	60–59	35–49	1–34	$T_{observ.}$
	CG_{before}	Q_{1i}	8	35	42	53	44	7	0	
	CG_{after}	Q_{2i}	8	27	32	41	39	5	0	
		Q_{2i}-Q_{1i}	0	-8	-10	12	-5	-2	0	
		T	0,19	3,53	4,4	5,3	2,4	0,0016	0	15,822

who studied without the use of the experimental method.

In the process of the experiment, we have investigated the definition of creativity among students of HEI, introducing a structural-functional model of teaching physical and technical disciplines and a methodology for teaching physical and technical disciplines on the basis of STEM education in conditions of transdisciplinarity.

To determine the creativity of beginning subjects in the process of teaching physics based on technology, we used Johnson's creativity questionnaire.

Johnson's questionnaire is an express method that allows you to quickly diagnose the creativity of study subjects. It is an objective checklist consisting of eight characteristics of creative thinking and behavior, which is designed to identify the manifestation of creativity in students of education.

To assess creativity according to Johnson's questionnaire, we observed the social interaction of subjects of study in the process of learning physics using modern means of STEM education. Each statement of the questionnaire is evaluated on a scale with five levels: 1 — never, 2 — rarely, 3 — sometimes, 4 — often, 5 — constantly. The overall assessment of creativity is the sum of points from eight points of the above criteria.

The results obtained by us regarding the definition of creativity in CG and EG are shown in Table 3.

In order to determine the creativity of the subjects of study according to the method of teaching physical and technical disciplines based on STEM technologies, in each group we selected subgroups of students, where their creative abilities were determined (Johnson's questionnaire) Table 3.

According to formula 1, for the significance of $\alpha = 0.05$ and the number of degrees of freedom $\nu = C - 1 = 5 - 1 = 4$, the critical value of the criterion statistic $T_{crit.} = 9.48$. According to the calculation result received by us, $T_{exp.} > T_{crit.}$ (20.97 > 9.48). So, according to the decision-making rules, we rejected the null hypothesis.

The obtained result makes it possible to conclude that the proposed method of teaching physics based on the technologies of the STEM education system gives more effective results than the traditional one.

Conclusions and prospects for further explorations in this direction. Taking into account modern trends and the main directions of improvement of the educational process, the created methodology for teaching physical and technical disciplines based on STEM technologies is aimed not only at high-quality, scientifically and methodologically grounded teaching of the content of the basics of Physics, which is provided by the educational activity of the teacher, but mainly at the activation of independent educational and research activities of the student of education using STEM technologies. Such a technique should develop and stimulate interest in knowledge and understanding of physical and technical disciplines based on STEM education in conditions of transdisciplinarity,

Table 3

Determining the levels of students' creativity in the process of learning Physics based on STEM technologies

Group	Very low level 8–14	Low level 15–19	Intermediate level 20–26	High level 27–33	Very high level 34–40
EG (353 respondents)	50	80	125	63	35
%, creativity in EG	14,2%	22,7%	35,4%	17,8%	9,9%
CG (341 respondents)	73	98	116	41	13
%, creativity in CG	21,4%	28,7%	34,01%	12,02%	3,8%
Δ, the difference between the value of % creativity in EG and CG	–7,2%	–6%	+1,39%	+5,78%	+6,1%
$T_{exp.}$	5,13	2,5	0,1	3,9	9,34
				The general value of $T_{exp.}$	20,97

their application in explaining the phenomena and processes of the microcosm and the surrounding world as a whole, and give students of education an effective system of soft skills and form a natural and scientific worldview. The results of the formative experiment showed positive changes in all performance indicators of the proposed structural-functional model of teaching physical and technical disciplines based on STEM education and the developed methodology of teaching physical and mathematical disciplines using STEM technologies and confirmed the main provisions of the goal and the proposed hypothesis.

In the future, research on this problem can be carried out in the following directions: development of a new approach to changing the structure and content of curricula; improvement of the content and system of teaching Physics taking into account new pedagogical technologies; strengthening the connection between the teaching of the physics course and the professional orientation of students of non-physics majors of technical HEI in the context of STEM education.

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СТРУКТУРНО-ФУНКЦІОНАЛЬНА МОДЕЛЬ НАВЧАННЯ ФІЗИКО-ТЕХНІЧНИХ ДИСЦИПЛІН НА ЗАСАДАХ STEM-ОСВІТИ: АСПЕКТ ТРАНСДИСЦИПЛІНАРНОСТІ

Анотація. *Розвиток інноваційності впливає на модернізацію вищої освіти, зокрема технічної, в контексті STEM-освіти. Відзначено, що модернізація вищої освіти в Україні потребує врахування загальних тенденцій розвитку систем вищої освіти у контексті глобалізаційних та євроінтеграційних процесів. Обґрунтовано доцільність структурно-функціональної моделі навчання фізико-технічних дисциплін на засадах STEM-освіти в умовах трансдисциплінарності. Установлено, що зміна в сфері вищої освіти, зокрема технічної, з урахуванням розвитку STEM-освіти передбачає перегляд концепції підготовки спеціалістів у кожній конкретній галузі діяльності, тому модернізація змісту освіти вимагає оновлення навчально-методичної бази (цілей, змісту, методів, форм і засобів), через яку надалі буде здійснюватися реалізація сучасних інноваційних підходів. Дістала розвитку експериментальна складова вивчення фізичних явищ за рахунок збільшення кількості різних видів дослідів (кількісних і якісних) у фізичному експерименті з використанням STEM-технологій (нові фізичні комплекти, ІКТ, 3-D моделювання та ін.). З урахуванням сучасних тенденцій та основних напрямів удосконалення освітнього процесу з метою ефективного ознайомлення студентів із основами фізики створена методика навчання фізико-технічних дисциплін, що потрібно для подальшого вивчення дисциплін професійного напряму. Ця методика повинна бути спрямована не тільки на якісне, науково й методично обґрунтоване викладання, що забезпечується навчальною діяльністю викладача, а й головним чином на активізацію самостійної навчально-пошукової діяльності студентів. Повинна розвивати й стимулювати інтерес до пізнання та розуміння фізики, до застосування цієї науки для пояснення явищ і процесів мікросвіту й навколишнього світу загалом і давати студентам дієву систему знань, умінь і навичок та формувати природничо-науковий світогляд. Результати проведеного порівняльного експерименту з виявлення ефективності запропонованої методики навчання фізико-технічних дисциплін у контексті STEM-освіти показали, що рівень сформованості фізичних знань, умінь і навичок здобувачів вищої освіти у контрольних групах є нижчим від відповідного рівня в експериментальних групах. Визначене за таблицею критичне значення* χ^2 *для прийнятого в педагогічних дослідженнях рівня значущості* $\alpha = 0,05$ *становить* $\chi^2_{crit.} = 12,59$; $\chi^2_{\exp.} = 13,3$, *тобто* $\chi^2_{\exp.} > \chi^2_{crit.}$ *та на основі критерію Колмогорова-Смирнова доводить до висновку* $T_{observ.} > W_{1-\alpha}$, *тобто (0,035 > 0,0003), а отже, розроблена методика навчання фізико-технічних дисциплін в умовах розвитку STEM-освіти є ефективнішою, ніж чинна.*

Ключові слова: *трансдисциплінарність, STEM-освіта, фізико-технічні дисципліни, структурно-функціональна модель, освітній процес.*

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