TRANSDISCIPLINARITY OF VOCATIONAL EDUCATION IN THE CONTEXT OF STEM-TEACHING OF PHYSICS

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Abstract

The innovative development of the educational and scientific field based on STEM education, in particular its professionally oriented environment, is determined by the principles of Industry 4.0. In the vector of the introduction of the methodology of a transdisciplinary approach to teaching physics and professionally oriented training of future aviation specialists, it is important to develop new methods of a professional orientation based on STEM technologies. The authors consider this problem as complex, which in the course of their research covers the justification of the relevance and feasibility of introducing STEM-approach (as a kind of transdisciplinary) in the educational process of higher education institutions using STEM technologies. Since, the solution of such problems, in particular the analysis of the specifics of physical phenomena and laws, which a priori are a fundamental part of mastering any profession, is impossible within a narrow discipline.

The purpose of the research is to theoretically substantiate the professional teaching of physics based on STEM technologies in transdisciplinary professional education and to develop appropriate methods that will provide training subjects with their active cognitive-exploratory, independent activities. This, in turn, helps to improve the quality of vocational education.

The concept of the research is the formation and development of STEM skills in future technical specialists in the process of teaching physics and outlines the principles of fundamentality based on transdisciplinarity of vocational education, taking into account the readiness of subjects to solve learning problems based on STEM technologies (3-D modelling, robotics kits, 3-D printing, augmented and virtual reality, etc.), which is now an important aspect for their training.

Taking into account the purpose and hypothesis of the research, the authors used the following methods:

theoretical (analysis of textbooks, manuals and publications that reflect the problem of research on STEM education and clarification of ontological and semantic connections in the context of the term «transdisciplinarity»;

specific pedagogical: methods of teaching physics that contribute to the study of modern physical scientific positions and achievements, trends in the development of physics in technical institutions of higher education);

empirical (diagnostic and sociometric methods) (observation, survey, content analysis) to determine the level of interest and activity of students in teaching physics and professionally oriented disciplines using STEM technologies);

pedagogical experiment, experimental verification of methods of teaching physics and professionally oriented disciplines based on STEM technologies, taking into account the professional orientation of the content of education.

The reliability of scientific results and conclusions is provided by: methodology of initial positions of research, conformity of research methods to its purpose, representativeness of the sample, various approbation of basic provisions of scientific research in pedagogical experiment and introduction of the developed technique of teaching physics and professionally oriented disciplines. acquisition of a profession), discussion of theoretical positions and concrete results of researches among like-minded people at various scientific and practical events (conferences and scientific seminars), application of a complex of research methods. The total number of participants in the experimental study is 532 students (including 254 control groups and 278 – experimental).

The transdisciplinary strategy of this research is outlined in the following areas: improving the content and system of professionally oriented teaching of physics, taking into account the principles of the digital age; strengthening the connection between the teaching of physics courses and the professional orientation of students of higher professional education in non-physical specialities based on a transdisciplinary approach.

The authors also emphasize the need to introduce comprehensive transdisciplinary research in the scientific and educational space based on the STEM approach and the implementation of the best results in the practice of vocational education.

Keywords: transdisciplinarity, STEM education, physics, aviation vocational training, professionally oriented disciplines, institutions of higher education, vocational education, digitalization.

1 INTRODUCTION

Conceptually, the development of effective national economic systems prioritizes the implementation of a consistent state educational policy aimed at intensifying innovation processes, forming an appropriate culture of society, strengthening the scientific and educational (intellectual) potential of the country. This should contribute to the competitiveness of modern education in the global market of technology, scientific knowledge and human resources. Ensuring such direction of education development will be carried out under the condition of public perception of the formation of new educational structures, namely the introduction of STEM-oriented approach based on transdisciplinary, modernization and reform of socio-pedagogical systems taking into account European standards, the introduction of flexible educational programs, the subjects of the educational process have critical and creative thinking, creativity and a positive attitude to innovation [1].

Transformational changes that enable the innovation of education are a defining characteristic of scientific and technical, industrial, socio-economic, socially advanced perestroika. After all, the transition to an innovative type of development of higher education institutions, in particular taking into account the transdisciplinary features of STEM education is of great socio-economic and humanistic significance. It is because today the main attention is paid to the process of transforming higher education from agents of scientific, technological and social progress into its real subjects, which encourages the development of the creative potential of each person for its implementation in a competitive environment [2].

It should be noted that the study of the term «innovation» began in the early twentieth century in line with the development of economic and sociological sciences. Of course, the founders of the theoretical foundations of innovation as a new field of scientific knowledge then became H. Tard [3], M. Kondratiev [4], Y. Shumpeter [5]. According to them, the essence of innovation as such is not only to meet existing needs but also to produce new ones aimed at changing the needs of human life. It should be noted that H. Tard rightly notes that the development of innovations can be carried out not only through adaptation and imitation but also through conflicts, the struggle between tradition and innovation [3]. In the same sense, the experience of I. Bohdanova becomes interesting, who on the principle of innovation potential identifies such innovations [6] as improving, related to the modification, rationalization, modernization; radical, related to the transformation of the traditional education system into an alternative one; complex, covering elements of improvement and transformation. Characteristic features of these innovations are the scale of their consideration in the education system and the innovativeness of their potential [6], namely: at the macro level there is a transformation of innovations; at the meso level - staffing in the main areas of related innovations in each component of the education system; at the micro-level - modernization, modification and rationalization of the traditional pedagogical process, which determines the locality or singularity of innovations that are not related to each other, i.e. changes that lead to element-by-element changes.

In this context, we note that research in the direction of STEM-approach has attracted the attention of many researchers. For example, didactic features of STEM education are outlined by I. Slipukhina [7; 8]; an adaptive socio-pedagogical system of STEM-knowledge management in the context of a transdisciplinary approach was proposed and substantiated by M. Rostoka and G. Cherevychnyi [9; 10]; theoretical and methodological principles of teaching physics on the basis of STEM-technologies in technical institutions of higher education according to the developed author's method were introduced into educational practice for the first time O. Kuzmenko [11]; the essence of STEM education and prospects for its development in the European Union (EU) and the United States of America (USA) as a new direction in science related to the introduction of promising innovative educational technologies and methods considered by such scientists as: O. Kovalenko, O. Saprunova [12]; substantiation of influence of means of STEM-training on realization of research-experimental, design, inventive activity in educational process of out-of-school education is presented by such researchers, as: O. Lozova, S. Gorbenko and N. Honcharova [13]; the methodological bases of STEM-education introduction are characterized and the regularity of creation of STEM-centers, STEM-programs within the framework of education reforming by O. Patrikieieva is substantiated [14]; the concept of digital didactics in the development of STEM-education was revealed by I. Chernetskyi [15]. Thus, considering the levels of integration of scientific knowledge, V. Sydorenko distinguished the directions of scientific research to solve problems of transdisciplinarity [16]: intradisciplinary (within certain sciences, such as physics, higher mathematics, avionics, etc.); interdisciplinary (within two or three branches of science: physics and professionally oriented disciplines – electrical engineering and radio electronics, technical mechanics, flight safety, etc.); superdisciplinary (high degree of integration, namely physics as an applied discipline of studying professionally oriented disciplines on the basis of STEM-education); transdisciplinary (integration of scientific concepts, theories of methods and techniques in philosophical concepts in the teaching of physics).

Appreciating the research of the above-mentioned scientists on the basis of our analysis of their work, it is established that today: there are almost no systematic holistic theoretical studies of the problems of transdisciplinarity of both physics and professional disciplines, which is the basis of STEM education (because transdisciplinarity is one of the fundamental features of modern science, which combines theoretical knowledge into a holistic system, reflects the active world in its unity and development in physics and in professional disciplines); there is practically no completed theory and methods of teaching physics to students in technical institutions of higher education based on STEM technologies.

Accordingly, analyzing the identified problems in the methodology of teaching physics and professionally oriented disciplines based on STEM-technologies in a transdisciplinary information and educational environment of technical institutions of higher education, identified and outlined certain contradictions between:

– the existing needs of society in highly qualified specialists, able to quickly adapt to the requirements of the modern labor market, and insufficient compliance with the content of training of future specialists in the technical field of training in the context of STEM-education;

– the prevalence of traditional methods of teaching physics and professionally oriented disciplines in technical institutions of higher education and the potential challenges of today to take into account the capabilities of the latest STEM-direction in the methodology of teaching physics;

– rapid transformational changes and technical and technological changes in society, encouraging the introduction of innovative approaches to teaching physics, and their fragmentation in the formation of strong and deep knowledge in the formation of professional STEM-competence of future professionals in a transdisciplinary approach.

Thus, from the standpoint of innovation in the teaching of physics on the basis of STEM education in transdisciplinary information and the educational environment of technical institutions of higher education, we focus on the results of training highly qualified professionals who will have the appropriate level of professional STEM-competencies, including technical direction. At the same time, at the present stage of postmodern education, the ability and readiness of higher education teachers to teach in complex problem situations related to practical activities using a transdisciplinary approach in the context of STEM education become relevant. Here it is appropriate to consider the interdisciplinary relationships of physics with disciplines of professionally oriented direction, where higher education students form subject competencies.

In this context, we state that the innovative activity and fundamentalization of physical education based on the STEM approach is an integral and important component of the professional competence of future professionals. For these reasons, the teaching of physics involves the formation of a system of fundamental physical knowledge and skills of applicants for higher technical education in the study of disciplines of professionally oriented direction and the application of acquired opportunities in their own lives.

It is obvious that the trends associated with innovation, digitalization, significantly affect the introduction of STEM-technologies in the education of higher education. Taking them into account allows to determine the basis for the development of a methodological system of teaching physics in the development of STEM education, which, in our opinion, should improve the quality of their physics education in a transdisciplinary paradigm for further mastering disciplines (navigation; meteorology; basics aviation geography; meteorology and ecology; basics of aeronautics and aviation cartography; aircraft and the basics of flight theory, etc.)

2 METHODOLOGY

The purpose of the study is to theoretically substantiate professionally oriented teaching of physics-based on STEM technologies in the conditions of transdisciplinarity of education and to develop on this basis an appropriate methodology that will provide students with their active cognitive, independent activities. This, in turn, helps to improve the quality of vocational education.

The concept of the research is the formation and development of STEM competencies in future technical specialists in the process of professionally oriented teaching of physics, and also outlines the fundamentals of the transdisciplinary approach to vocational education. This takes into account the readiness of the subjects of the educational process (teachers and students) to solve educational

problems based on STEM technologies (3-D modelling, robotics kits, 3-D printing, augmented and virtual reality, etc.). is an important aspect for the effective organization of training of future professionals.
Taking into account the purpose and hypothesis of the study, the authors used the following methods: theoretical analysis of textbooks, manuals and publications that reflect the problem of STEM education and clarification of ontological and semantic connections in the context of the term «transdisciplinarity»; specific pedagogical: teaching methods physicists who contribute to the study of modern physics scientific positions and achievements, trends in the development of physics in technical institutions of higher education); empirical (diagnostic and sociometric methods) (observations, surveys, content analysis) to determine the level of interest and activity of students in teaching physics and professionally-oriented disciplines using the STEM approach); pedagogical experiment, experimental verification of the author's methods of teaching physics and professionally-oriented disciplines based on STEM technologies, taking into account the professional orientation of the content of education.
The theoretical significance of the expected results includes: 1) conducting theoretical and logical-methodological analysis of the problem of development of teaching physics based on STEM-approach based on transdisciplinarity; 2) determination of the content of methods of using fundamental theories of the general course of physics in the context of possibilities of STEM technologies and their theoretical generalization taking into account transdisciplinary connections with disciplines of professionally oriented training; 3) creation of a methodical system of formation of physical knowledge in students taking into account the transdisciplinary approach with technical disciplines based on STEM management, which is based on the relationship of symmetry and asymmetry and corresponding methods of students' activities in teaching physics in technical institutions of higher education (HE).
The practical significance of the expected results is developed and implemented in the practice of the educational process of technical free economic zones: textbook «Method and Technique of Experiment for Optics» [17], textbooks: «Interferometers. Physical workshop on optics with new and non-traditional equipment» [18], «Physics. Mechanics. Molecular Physics and Thermodynamics, Electromagnetism. Oscillations and wave optics. Quantum and Atomic Physics» [19], «Physics. Manual for laboratory work» [20], guidelines for laboratory work and practical classes using STEM technologies (Mechanics and molecular physics. Guidelines for laboratory work in physics based on the set «L-micro «for cadets of the academy of all specialities» [21], «Physics. Methodical instructions for performing computational and graphic work in physics (work № 1)») [22], in particular in English for students of technical institutions of HE.
The results of the research were tested in the process of organizing and conducting the International scientific-practical seminar «STEM-education – problems and prospects» (2016-2018) [23]; International scientific-practical conference «Actual aspects of the development of STEM-education of natural sciences» (2018-2021) [24] and the all-Ukrainian festival «STEM-SRING-FEST» (2017-2021).

3 ДИСКУССИЯ

The definition of «transdisciplinarity» was proposed to the scientific circulation of Z. Piazhe (1972): «them, overcoming persistent disciplinary barriers» [16]. In our opinion, the post-pandemic world once again provides grounds for actualizing Z. Piazhe's thoughts.
E. Yanch stressed that transdisciplinarity as a «new space without stable boundaries between disciplines», as a new field of knowledge, must be super- or hyper disciplined, it must be the coordinator of all disciplinary and interdisciplinary systems of learning and innovation based on a common axiomatic approach [17]. In this vector, Ukrainian scientists began to unite like-minded people in the modern circle of the international scientific-practical web forum «Development of a single open information space for lifelong learning» [25]. In addition, the philosophy of a transdisciplinary approach to the creation of information and educational environments is presented through the introduction of appropriate methodologies based on the philosophy of transdisciplinarity, which erases the communicative and cognitive boundaries between certain disciplinary knowledge [10].
Note that the concept of «transdisciplinarity» A. Likhnerovych defined through «cross-games», able to describe «the homogeneity of theoretical activities in different fields of science and technology, regardless of the field where this activity is carried out» [26]. And, of course, this theoretical activity could be formulated only in mathematical language, which in turn reveals a component of STEM educational training.
Thus, the term «transdisciplinarity» is considered by researchers on various grounds. In the first sense, transdisciplinarity is proposed to be interpreted as a «declaration» that proclaims the equal rights of known and little-known scientists, large and small scientific disciplines, cultures and religions,

in the study of the world [28]. In the second sense, «transdisciplinarity» is interpreted as a high level of education, versatility, universality of knowledge of a particular person [29]. In the third sense, it is the «rule of studying the world around us» (the option is considered that transdisciplinarity will be implemented if the problem is studied at several levels, such as physical and mental, globally and locally [26]. Thus, in the analysis of these sources) in the system of transdisciplinarity we distinguish four main trends:

1. The first is based on the modern version of the epistemological search for systematic integration of knowledge, the roots of which go back to ancient Greece, medieval Christianity, the principles of universal causality of the Enlightenment, Hegel's philosophy, unified physics theory and others.
2. The second trend is based on the synthetic paradigm of postmodern content.
3. The third trend follows from the critical direction of interdisciplinary research, considering transdisciplinarity not only as a transition to a new quality but also overcoming existing disciplinary boundaries (transgression).
4. The fourth trend is caused by the concept of postnormal science and the «second method» of obtaining knowledge, which is based on the principles of logic, cybernetics, general systems theory, structuralism, organizational theory (inherent complexity, nonlinearity, heterogeneity, etc.) – public discussions with steak participants to obtain «reliable scientific knowledge» and «socially healthy knowledge».

In the fourth sense, «transdisciplinarity» is used as a «principle of organization of scientific knowledge», which opens wide opportunities for interaction of many disciplines in solving complex problems of nature and society [30]. Note that transdisciplinarity, in this sense, allows scientists to officially go beyond their discipline without fear of being accused of dilettantism.

Transdisciplinarity is understood as non-scientific knowledge that does not form an array of scientific disciplines but is used in popular science programs. The problem of identifying transdisciplinarity resonates with the problem of its differentiation, in particular in comparison with other similar concepts. Therefore, the term «interdisciplinarity» means, first of all, the cooperation of different scientific disciplines, the use of common concepts and explanations of certain actions or objects [31].

Taking into account the results of research by the Belgian scientist E. Dzhadzh [27], we define four types of transdisciplinarity that should be used in the process of teaching physics based on STEM technologies in HE institutions of technical profile: 1) transdisciplinarity-0: illustrative use of metaphor; 2) transdisciplinarity-1: based on the efforts of the formal interconnection of understandings of individual disciplines of professionally oriented direction. It provides the formation of logical meta-frameworks through which their knowledge is integrated at a higher level of abstraction than is the case in interdisciplinarity. Transdisciplinarity-1 is used in the work of expert systems and groups; 3) transdisciplinarity-2 provides an internal connection with the personal experience of the researcher. 4) transdisciplinarity-3, associated with the use of general metaphors, which are focused on the fundamental cognitive value, in particular the study of end-to-end generating concepts based on STEM technologies.

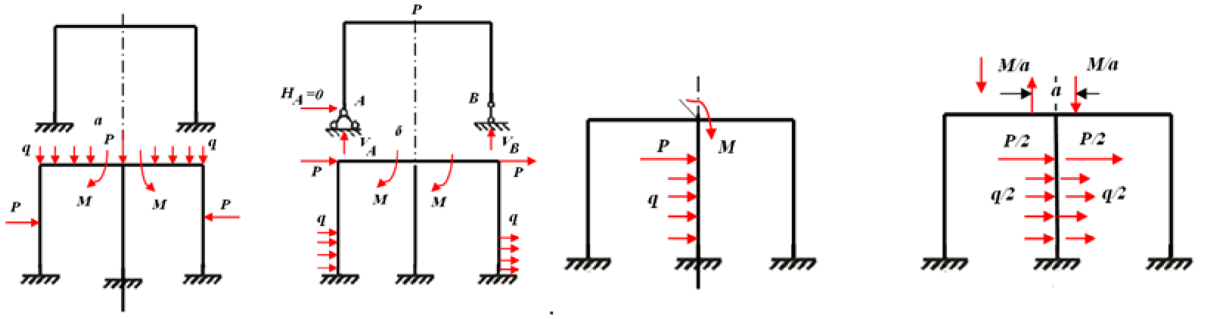
The nature of natural sciences to integration in the process of finding solutions to complex multifactorial problems of nature and society in the picture of a single world is realized in one of the varieties of transdisciplinary approaches - transdisciplinarity-4. Transdisciplinarity-4, according to V. Vakhshtain's interpretation, is a way of knowing the world that provides an opportunity to reduce the knowledge of mankind into a comprehensive, coherent science based on a single set of concepts and metalanguages [33]. In this way, transdisciplinarity-4 is similar to hyperdisciplinarity or metascience [34, p. 43–110]. Important factors in the fundamentality of natural sciences are the components of metascience: metatheory [35, p. 491–492] and metanarratives [36, p. 489–490].

The metatheory of transdisciplinarity-4 is a description of general ideas about the fundamental features of the world order and the forms of their manifestation, which form the basis of the whole system of human knowledge about the surrounding reality. The set of initial worldviews and basic philosophical categories within the metatheory of transdisciplinarity-4 is subjected to intellectual processing, which leads to their rethinking, ordering and generalization. Metatheory of transdisciplinarity-4 - creating a picture of a single world. Disciplinary pictures of the world in this case are abstract models of certain areas (fragments) of a single world. As a result, the metatheory of transdisciplinarity-4 is outlined by a scheme that determines the method and context of constructing scientific models of the studied areas (fragments) of reality, and also sets a set of most general conditions that provide a way to understand special theories constructed by scientists. This scheme, due to its abstractness, provides a transdisciplinary interpretation of the results of modelling fragments of reality in different disciplinary and interdisciplinary approaches.

Metanarratives of Transdisciplinarity-4 is a universal system of concepts, signs, symbols and models, aimed at creating a single type of description of objects and presentation of interrelated events in the picture of a single world. The metanarrative of transdisciplinarity-4 combines different concepts of natural sciences, as well as areas of interaction. In this regard, the metanarrative of transdisciplinarity-4 is formed in the process of philosophical rethinking of general concepts and categories that are necessary and sufficient to describe the picture of a single world.

4 RESULTS

Consider, as an example, the use of the fundamental physical concept of «symmetry» in the process of students mastering the content of the disciplines «Physics», «Theoretical Mechanics» and «Resistance of materials» with the selection of basic STEM components in a transdisciplinary learning paradigm.
Note that the system is called symmetric about the axis, if, using a line that coincides with the axis of symmetry, it can be divided into two parts, each of which is a mirror image of the other (Fig. 1).



a) b) c) d)
Figure 1. Image of frames in the process of symmetrical and obliquely symmetrical system

In addition to symmetric, there are not entirely symmetrical systems that can be considered symmetrical under certain conditions. If we consider the frame (Fig. 1, a), which is not completely symmetrical because it has a hinged fixed resistance on the left, and on the right – hinged, under vertical load can be considered symmetrical because the horizontal reaction of the left support is zero and this support can be interpreted as articulated. Systems of this type are called conditionally symmetric. The concept of symmetry extends to the load, the action of temperature, the displacement of the supports: the action is considered symmetrical if it is on one half of the structure is a mirror image of the action on the other half (Fig. 1., b). If the action is located symmetrically, but with the axis of symmetry in opposite directions, then such an action is called obliquely symmetric or inversely symmetric (Fig. 1., c). Accordingly, the concentrated force *P*, the line of action of which coincides with the axis of symmetry, is symmetrical, and the concentrated force or distributed load, which is applied to the axis of symmetry and directed perpendicular to it, is obliquely symmetrical. Similarly, we can consider (Fig. 1, c), relative to the concentrated moment. This is because the concentrated force *P* can be represented as two concentrated forces of *P/2*, the distributed load relative to q – as two loads with intensity *q/2* each, and the concentrated moment *M* can be replaced by a pair of forces (Fig. 1, d).
In the process of performing the proposed task with students, STEM components (scientific, technical, engineering, mathematics) were identified. According to this example, we see that physics is related to the study of the basics of theoretical mechanics, higher mathematics, avionics and elements of flight dynamics, as, for example, the study of symmetry is important for considering the structure of the wing of an aircraft. Starting my research, it is hypothetically established that the theoretically developed and methodologically sound principles of physics teaching methods based on STEM technologies in the HE of technical training and its introduction will provide a scientifically sound selection of physics content, which, in turn, will increase efficiency learning provided that the educational process is based on integrated, interdisciplinary, competence and systemic approaches. At the same time, it is accompanied using information and communication technologies and their optimal combination with the appropriate methodological support.
Agreeing with the opinion of N. Tverezovska and V. Sydorenko [37] that the research hypothesis will perform its function only when it meets the following conditions: 1) be a reasonable prediction, not a hasty assumption; 2) be simple and clear in wording; 3) be an adequate answer to the question; 4) correspond to the facts based on which it is formulated and to explain which it is intended; 5) take into account previously discovered patterns, but do not contradict the already known research results; 6) explain a certain range of phenomena of reality; 7) anticipate new facts, phenomena and connections between them; 8) be subjected to empirical verification.

Our assumption about improving the methodology of teaching physics in the development of STEM education is not only the need to form in higher education a certain system of knowledge, skills and abilities but also, respectively, helps to raise the role of each student and each teacher in the study of physics cognitive, independent activity; provides development of thinking and creative abilities; satisfies the requests and wishes, inclinations and plans for the future of each person; uses such practical and experimental tasks in terms of content and scope, which will have practical application in the process of studying physics in educational institutions.
It should be noted that technical institutions of HE were selected for the experiment, the physics laboratories of which were better equipped with equipment for staging an educational physical experiment based on STEM education technologies, which corresponded to the conditions of optimality. In these free economic zones, scientific work in physics was also carried out with students at the appropriate level, which contributed more to the conduct of the experiment and created the necessary conditions in the context of the development of STEM education. The groups were selected in such a way that they corresponded to the conditions of the pedagogical experiment, namely the number of students in the groups. Experienced scientific and pedagogical workers worked in the selected free educational institutions of the technical profile, who expressed their desire and readiness to work according to the proposed method of teaching physics based on STEM technologies in the conditions of transdisciplinarity.
For statistical processing of results of a forming stage of the pedagogical experiment the methods of check of statistical hypotheses based on comparison of measurements of some property at two independent samples are applied: 1) criterion χ^2; 2) the Kolmohorov-Smirnov criterion.
The criterion χ^2 was used to compare the distributions of objects of two sets by the state of some property. The effectiveness of test works on the physics of experimental (EG) and control groups (CG), which were introduced in HE technical profile, namely Vinnytsia National Technical University, Kremenchuk National University named after Mikhail Ostrogradsky (materials were tested at the Department of Biotechnology and Bioengineering), Aviation University (materials tested at the Faculty of Flight Operations, Faculty of Air Traffic Services and Management), National Aviation University (materials tested at the Department of General Physics), Cherkasy National University named after Bohdan Khmelnytskyi (materials tested at the Department of Automation and Computer-Integrated Technologies) Institute of Information and Educational Technologies).
The results of the comparative stage of the experiment to identify the effectiveness of the proposed method of teaching physics in the context of STEM education showed that the level of physical knowledge, skills and abilities of students in control groups is lower than the corresponding level in experimental groups. The critical value χ^2 determined according to the table for the level of significance accepted $\alpha = 0{,}05$ in pedagogical researches makes $X^2_{cr}=12{,}59$; $X^2_{ex}=13{,}3$, ie. $X^2_{ex}> X^2_{cr}$ and based on the Kolmohorov-Smirnov criterion leads to the conclusion, $T_{exp}>W_{1-\alpha}$ ie. (0.035> 0.0003), ie the developed method of teaching physics in the development of STEM education is more effective than the existing one. This testifies to the effectiveness of the considered equipment, software and pedagogical support and methodological support for it.
To establish the depth and strength of the formed knowledge of students of experimental groups during the pedagogical experiment, the results of control and test tasks in physics were analyzed. According to this purpose, the learning outcomes were assessed by the level of mastering theoretical questions in the fields of physics and by the skills and abilities that were formed during the solution of physical problems (Fig. 2). and works of the physical workshop, their generalization is presented in the form of a diagram in Fig. 3.

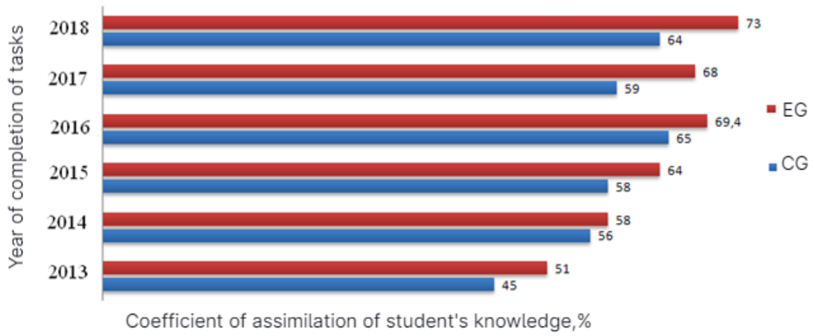


Figure 2. Dynamics of formation of STEM knowledge and STEM skills in student’s in solving physical problems in EG and CG groups

Analyzing this diagram, we can conclude that students' knowledge of physics in experimental groups is strong and deep in the process of applying the proposed method of teaching physics in experimental classes. In particular, it is a deep understanding of the essence and quality of experimental mapping using new tools in physics: the work of the physical workshop (the coefficient of knowledge acquisition is 67.3%) using modern STEM technologies. Execution of laboratory works (works of the physics workshop), their generalization is presented in the form of the diagram in fig. 3.

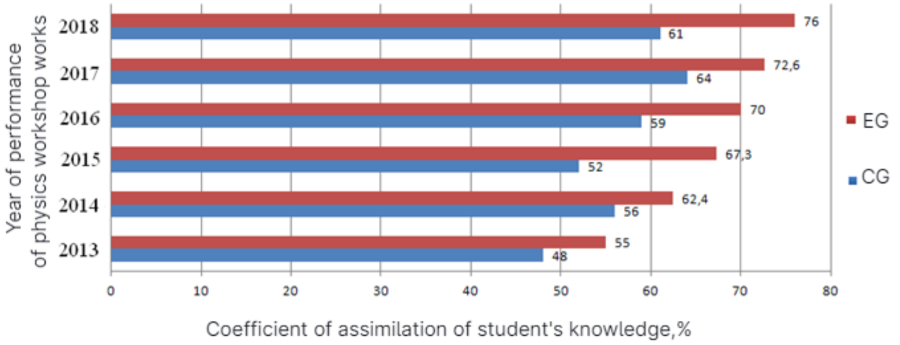


Figure 3. Dynamics of formation of STEM knowledge and STEM-skills of students at the performance by them of works of a physical workshop in EG and KG groups

At a sufficient level (the coefficient of mastering the educational material 73%) were the skills and abilities of students acquired during the solution of physical problems. It should be noted the use of software and pedagogical software, namely a set of «L-micro» [21] (coefficient of learning material 76%). This allows us to talk about the effectiveness of the proposed guidelines for physics in the context of STEM education.

The results of the pedagogical experiment confirm the effectiveness and significance of the methodology of teaching physics based on STEM technologies in transdisciplinarity, namely the organization of students' practical tasks, the formation of skills and abilities in the process of performing physical workshops based on STEM-education technologies.

5 CONCLUSIONS

In the course of the study, the authors found that the change in higher education, including technical, taking into account the development of STEM education involves revising the concept of training in each field, so modernizing the content of education requires updating the teaching base (goals, content, methods, forms and means), through which in the future will be the implementation of modern innovative approaches.

The essence of the concept of «transdisciplinarity» in the process of teaching physics based on STEM education in technical institutions of higher education is analyzed and highlighted. It is shown that the method of using modern technologies during physics classes with students of non-physical specialities of technical universities allows them to develop STEM competencies in physics. The expediency of subordinating the content of educational material in physics, based on fundamental concepts, one of which is symmetry, which is considered in many sections of physics, is considered. Accordingly, acquaintance and study of this concept by students will contribute to the formation of modern scientific thinking, as well as provide systematization of knowledge from the general course of physics in higher education and the formation of a professional scientific worldview. Some works of the physics workshop with the use of STEM technologies from all sections of the physics course have been developed, which contribute to the effective conduct of classes in HEI of the technical profile of training. Among them are: «Mechanics», «Molecular Physics and Thermodynamics», «Electrostatics», «Electric Field», «Electrodynamics», «Magnetic Field», «Electromagnetic Oscillations», «Electromagnetic Waves», «Optics», «Atomic and nuclear physics» [28-31].

The results of the pedagogical experiment showed an improvement in all indicators of the effectiveness of the developed methodology of teaching physics based on STEM technologies in a transdisciplinary approach and confirmed the main provisions of the goal and the hypothesis. In the future, research on this issue can be conducted in the following areas: development of a new approach to changing the structure and content of curricula; improving the content and system of teaching physics, taking into account digitization technologies; strengthening the connection between the teaching of physics course and the professional orientation of students of non-physics specialities of technical institutions of HE in the context of STEM education.

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