THE IMPACT OF INNOVATIVE STEM EDUCATION TECHNOLOGIES ON THE QUALITY OF LEARNING OF EDUCATIONAL MATERIAL

O IMPACTO DAS TECNOLOGIAS DE EDUCAÇÃO DE TRONCO INOVADORAS NA QUALIDADE DE APRENDIZAGEM DO MATERIAL EDUCACIONAL

EL IMPACTO DE LAS TECNOLOGÍAS DE EDUCACIÓN STEM INNOVADORAS EN LA CALIDAD DEL APRENDIZAJE DEL MATERIAL EDUCATIVO

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ABSTRACT: The peculiarity of professionally oriented training of applicants for higher education based on STEM technologies is the need to take into account interdisciplinary connections as a manifestation of integrative processes of penetration of fundamental disciplines (physics), natural and mathematical knowledge into the cycle of subjects of professionally oriented training of students, which is provided not only by basic physical, mathematical and technical competencies of the 21st century but also by key methodological knowledge taking into account applied aspects. These connections play a leading role in improving the quality of professionally oriented training of future specialists. The purpose of the article is to determine the impact of innovative technologies of STEM education on the quality of learning of educational material through a physical experiment. The article experimentally substantiates the effectiveness of using the STEM approach when performing laboratory work to form the studied physical concepts in comparison with traditional teaching methods. It has been shown that the use of the STEM approach improves the level of assimilation of concepts in comparison with traditional teaching methods. In the case of using the STEM approach, the number of students with a high level of assimilation of concepts increases significantly, while the number of students with a low level decreases, which proves the effectiveness of using the STEM approach for the formation of high-level knowledge and skills. The article highlights the features of the formation of the STEM component in teaching in the innovative educational and scientific environment of the technical university, as well as the features of the teaching methodology taking into account STEM-learning technologies. It has been concluded that the use of the STEM approach significantly improves the level of assimilation of physical concepts in comparison with traditional teaching methods.

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KEYWORDS: STEM-learning. STEM-technologies. STEM-environment. STEM-approach. Physics. Laboratory work. Scientific concepts.

RESUMO: *A peculiaridade da formação profissionalmente orientada de candidatos ao ensino superior com base em tecnologias STEM é a necessidade de levar em consideração as conexões interdisciplinares como manifestação de processos integrativos de penetração das disciplinas fundamentais (física), do conhecimento natural e matemático no ciclo das disciplinas da formação profissionalmente orientada dos alunos, proporcionada não apenas pelas competências físicas, matemáticas e técnicas básicas do século XXI, mas também por conhecimentos metodológicos fundamentais tendo em conta aspectos aplicados. Essas conexões desempenham um papel fundamental na melhoria da qualidade da formação profissionalmente orientada de futuros especialistas. O objetivo do artigo é determinar o impacto de tecnologias inovadoras de educação STEM na qualidade de aprendizagem do material educacional por meio de um experimento físico. O artigo comprova experimentalmente a eficácia do uso da abordagem STEM ao realizar o trabalho de laboratório para formar os conceitos físicos estudados em comparação com os métodos de ensino tradicionais. Foi demonstrado que o uso da abordagem STEM melhora o nível de assimilação dos conceitos em comparação com os métodos tradicionais de ensino. No caso do uso da abordagem STEM, o número de alunos com alto nível de assimilação de conceitos aumenta significativamente, enquanto o número de alunos com baixo nível diminui, o que prova a eficácia do uso da abordagem STEM para a formação de nível de conhecimento e habilidades. O artigo destaca as características da formação do componente STEM no ensino no ambiente educacional e científico inovador da universidade técnica, bem como as características da metodologia de ensino levando em consideração as tecnologias de aprendizagem STEM. Concluiu-se que o uso da abordagem STEM melhora significativamente o nível de assimilação dos conceitos físicos em comparação com os métodos tradicionais de ensino.*

PALAVRAS-CHAVE: *Aprendizagem STEM. Tecnologias STEM. Ambiente STEM. Abordagem STEM. Física. Trabalho de laboratório. Conceitos científicos.*

RESUMEN: *La peculiaridad de la formación profesionalmente orientada de los aspirantes a la educación superior basada en tecnologías STEM es la necesidad de tener en cuenta las conexiones interdisciplinarias como manifestación de procesos integradores de penetración de disciplinas fundamentales (física), conocimientos naturales y matemáticos en el ciclo de asignaturas de la profesión. Formación orientada al alumnado, que se proporciona no solo por las competencias básicas físicas, matemáticas y técnicas del siglo XXI sino también por conocimientos metodológicos clave teniendo en cuenta aspectos aplicados. Estas conexiones desempeñan un papel fundamental en la mejora de la calidad de la formación profesional de los futuros especialistas. El propósito del artículo es determinar el impacto de las tecnologías innovadoras de la educación STEM en la calidad del aprendizaje del material educativo a través de un experimento físico. El artículo corrobora experimentalmente la efectividad de utilizar el enfoque STEM al realizar el trabajo de laboratorio para formar los conceptos físicos estudiados en comparación con los métodos de enseñanza tradicionales. Se ha demostrado que el uso del enfoque STEM mejora el nivel de asimilación de conceptos en comparación con los métodos de enseñanza tradicionales. En el caso de utilizar el enfoque STEM, el número de estudiantes con un alto nivel de asimilación de conceptos aumenta significativamente, mientras que el número de estudiantes con un nivel bajo disminuye, lo que demuestra la efectividad de* *usar el enfoque STEM para la formación de alto nivel. nivel de conocimientos y habilidades. El artículo destaca las características de la formación del componente STEM en la docencia en el entorno educativo y científico innovador de la universidad técnica, así como las características de la metodología de enseñanza teniendo en cuenta las tecnologías de aprendizaje STEM. Se ha concluido que el uso del enfoque STEM mejora significativamente el nivel de asimilación de conceptos físicos en comparación con los métodos de enseñanza tradicionales.*

PALABRAS CLAVE: *Aprendizaje STEM. Tecnologías STEM. Entorno STEM. Enfoque STEM. Física. Trabajo de laboratorio. Conceptos científicos.*

Introduction

Given the trends of teaching disciplines in recent decades (compliance of the educational process with modern trends in the educational sphere, especially due to the restrictions associated with the development of the COVID-19 pandemic, the introduction of computer, mobile and remote technologies; active involvement of new educational equipment), the priority task of education is not so much the assimilation of a certain amount of knowledge, skills, and abilities, but the formation of competencies related to further professional activity. It is the use of STEM education, according to many studies (BLACKLEY; HOWELL, 2015; LOGACHEV *et al*., 2021; DALGARNO *et al*., 2009; VINICHENKO, *et al*., 2020), that will expand the opportunities for effective and high-quality professional training of future specialists, develop the ability to research, analytical work, experimentation, and critical thinking.

An urgent issue of innovative development of education is the development and implementation of modern teaching methods based on the principles of STEM education (HAN *et al.,* 2015), which will ensure the training of highly qualified specialists in the technical industry (KNEZEK; CHRISTENSEN; TYLER-WOOD, 2011). The effectiveness of didactics based on STEM education technologies provides for the adaptability of forms and methods of teaching in terms of their structure, design, and practical application, as well as to a certain extent the primary stage of designing the educational process – the formulation of tasks that need to be considered in the learning process.

Literature review

According to researchers, STEM education is a series or sequence of courses or training programs (BROWN *et al.,* 2011) that prepare applicants for successful employment, require different and more technically complex skills (HERNANDEZ *et al.,* 2014), in particular with the use of mathematical knowledge and scientific concepts (BECKER; PARK, 2011).

Based on the analysis of scientific literature, Table 1 presents the goals and methods of STEM education that should be considered in the process of preparing applicants for higher education.

Table 1 – The main goals and methods of STEM learning

Goals and methods		Source
Goals	The scientific and technical literacy of the subjects of training assumes a basic scientific understanding of the studied phenomena, their use in everyday technologies, and digital literacy. This goal is achieved through integrated learning, interdisciplinary connections based on the principles of STEM education	(LI, 2018; FREEMA; MARGINSON; TYTLER, 2015; MEYRICK, 2011)
	The scientific and technical potential of the subjects of training is aimed at improving technical competencies and provides for mastering the skills of computerized software and hardware in various forms of the educational and scientific STEM environment	(BASHAM; ISRAEL; MAYNARD, 2010; ENGLISH; KING, 2015; BREINER *et al.*, 2012)
	Modeling and design in the field of STEM education includes the development of special STEM skills that are formed in the learning process	(FREEMAN *et al.*, 2014; MALTESE *et al.*, 2015; ERDOGAN *et al.*, 2016)
Methods	Integrated, interdisciplinary STEM training (involving two or more disciplines) to provide a holistic education in the field of science and an educational and scientific STEM environment focused on STEM technologies. This is a synergistic combination of many disciplines that represent one new basis for teaching and studying disciplines with an emphasis on scientific research and problem solving	(DECOITO, 2016; LI; SCHOENFELD, 2019; MOORE; SMITH, 2014).
	Identification of the components of STEM education in the process of solving problems and performing practical work focused on the applied aspect of the industry	(ERDURAN; OZDEM; PARK, 2015; SAMPURNO; SARI; WIJAYA, 2015; SPELT *et al.*, 2009; TÜRK; KALAYC; YAMAK, 2018).

Source: Devised by the authors

The hypothesis of the study: the use of the STEM approach significantly improves the level of assimilation of the studied concepts in comparison with traditional teaching methods, promotes the development of creativity and artistic skills of students.

Research objectives:

- to select students of the experimental and control groups;
- to carry out experimental training of students of experimental groups using the STEM approach when conducting laboratory work in physics;
- to conduct quantitative processing and interpretation of experimental data;
- to formulate conclusions and prospects for further research.

The article consists of an introduction, a literature review, methods, results, discussion, and conclusion.

Methods

Research model

Regardless of the method of cognition, which is the basis of the process of teaching physics, an educational physical experiment is its mandatory element and at the same time an integral component of the methodology of teaching physics as a scientific discipline that can ensure effective assimilation of knowledge by subjects of training in the context of STEM education.

The importance of physical experiments in the educational process in the context of the development of STEM education follows from the fact that fundamental human activity is practical. Special attention is paid to laboratory work in the system of the educational physical experiment, which provides practical training for students in the process of studying physics as fundamental science. The main purpose of performing laboratory work is to familiarize students with the experimental method of studying physical phenomena, to form an understanding of the principles of measuring physical quantities, to master the methods and techniques of measurement, as well as methods of error analysis.

In this regard, an experimental study of the influence of the use of the STEM approach in teaching students was conducted in the process of performing laboratory work on the physics course by students of the 1st and 2nd years.

The devices of the Phywe digital laboratories were used to test the hypothesis and implement the STEM approach in teaching students. The main STEM modules of the German "Phywe" company include robotics, programming, elements of mechanics and statics, mathematical programs, production.

We also recruited four groups of students who studied at the first and second years of the bachelor's educational level, a total of 151 people. Students of the experimental groups of the first and second years (EG1, 40 people; EG2, 37 people) were studying physical concepts during laboratory studies developed based on the STEM approach and had the opportunity to use the devices of the digital laboratories "Phywe", including the coding set Arduino Brick'R'knowledge, designed to familiarize students with digital electronics and programming; a set of robotics (TÜRK; KALAYC; YAMAK, 2018), with which it is possible to easily start programming and determine the basic principles of robots; a set of Electronics Basic, designed to familiarize students with the most important variables and functional capabilities of electronic circuits.

Students of the control groups of the first and second years (CG1, 39 people; CG2, 35 people) mastered the studied phenomena and concepts by the traditional method of teaching, which was based on heuristic conversation and frontal laboratory work.

Empirical methods

Students of experimental and control groups were tested (an ascertaining experiment) to check the level of assimilation of the studied phenomena and concepts. The formative experiment consisted of checking the level of assimilation of the studied phenomena and concepts after laboratory work. The testing included 10 closed tests reflecting both the main theoretical foundations of the studied phenomena and concepts and their practical aspects.

Also, the results of students' educational achievements in mastering phenomena and concepts were considered according to the criteria of the formation of scientific concepts. The characteristics of the levels of formation of scientific concepts are determined by the corresponding levels of mental and cognitive activities: initial (reproductive), medium (intellectual and logical), high (creative).

The general structure of criteria for the levels of formation of scientific concepts among students, which is proposed to be used in the course of pedagogical assessment, is shown in Table 2.

Table 2 – Criteria for the formation of scientific concepts

Levels of formation of scientific concepts	The main characteristic of the criteria for the levels of formation of scientific concepts
1. Initial	The initial idea of the objects of the phenomenon, the possession of terms that denote the concept, the possession of individual signs of concepts
2. Average	Free use of terminology to denote concepts, possession of objects of concepts, understanding of the essence of phenomena, laws, relationships between concepts; operating with logical sequential actions to explain the essence of phenomena

3. High	The presence of productive creative thinking, the ability to predict events, phenomena; fluency in basic scientific concepts and terms, the ability to apply knowledge to solve ideological problems, the ability to independently establish cause-and-effect relationships between the main scientific concepts, the ability to make generalizations and ideological conclusions based on the possession of a system of basic scientific concepts

Souce: Devised by the authors

Mathematical processing of research results

The coefficient of knowledge assimilation k was used for mathematical processing of the obtained data:

$$k = (\Sigma I`_a / N I_a)\ 100\%$$

where *a* is the total number of knowledge elements to be tested, $\Sigma I'_a$ is the sum of the learned knowledge elements by students of the selected group, I_a is the number of learned knowledge elements that correspond to a certain level of formation and assimilation of scientific phenomena and concepts, N is the total number of students of the selected group.

Results

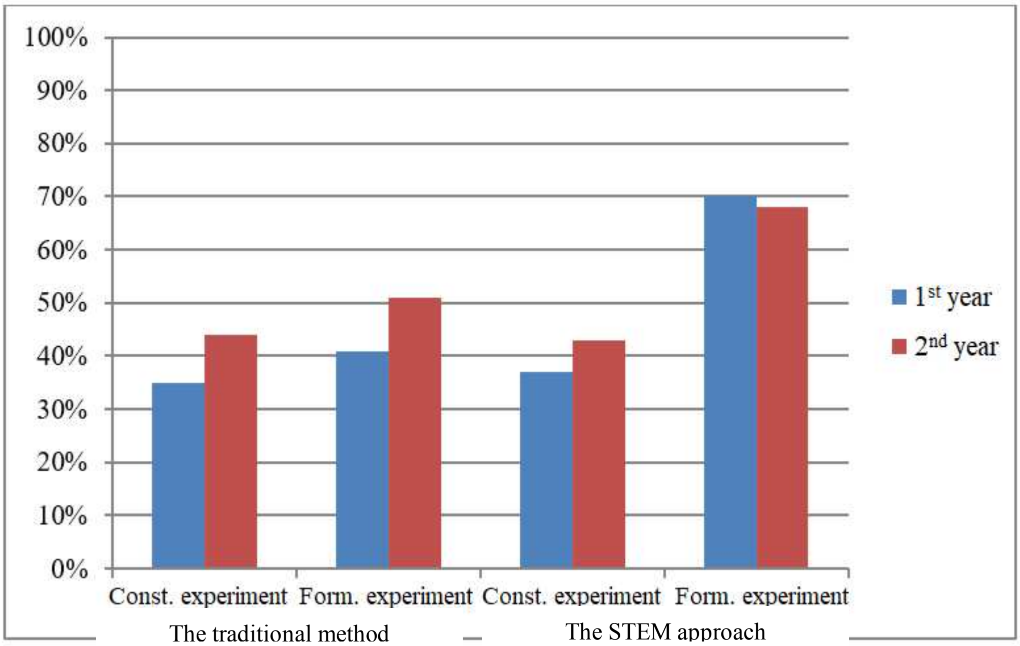
The results of the level of assimilation of the studied phenomena and concepts in the control and experimental groups are presented in Fig. 1 and Table 3.

Table 3 – Comparative results of the level of assimilation of the studied phenomena and concepts in the control and experimental groups

	Traditional training method (CG1, CG2)		STEM approach (EG1, EG2)	
	Const. experiment	Form. experiment	Const. experiment	Form. experiment
1st year	35%	41%	37%	70%
2nd year	44%	51%	43%	68%

Source: Devised by the authors

Figure 1 – The level of assimilation of the studied phenomena and concepts in the control and experimental groups



Source: Devised by the authors

Following the results of the experiment, the level of formation of the studied phenomena and concepts (stating experiment) the 1st-year students have less compared to the 2nd-year students. The results of the formative experiment suggest that the level of assimilation of the studied phenomena and concepts among 1st-year students who traditionally mastered them increased by 6% and with the help of the STEM approach by 33%. The corresponding indicators were 7% (traditional technology) and 25% (STEM approach) among the 2nd-year students. Thus, the efficiency of mastering phenomena and concepts using the STEM approach is higher for students of 1st-2nd years compared to traditional technology.

The evaluation of the effectiveness of the STEM approach in comparison with traditional teaching methods according to the criteria of educational achievements is presented in Table 4.

Table 4 – Criteria-based assessment of students' assimilation of the studied phenomena and concepts using the STEM approach and traditional teaching methods

	Traditional training method (CG1, CG2)				STEM approach (EG1, EG2)			
	Const. experiment		Form. experiment		Const. experiment		Form. experiment	
	Level	qty, %	Level	qty, %	Level	qty, %	Level	qty, %
1st year	low	26	low	16	low	20	low	10
	average	70	average	66	average	71	average	58
	high	4	high	18	high	9	high	32
2nd year	low	24	low	12	low	21	low	9
	average	68	average	68	average	69	average	49
	high	8	high	20	high	10	high	42

Source: Devised by the authors

According to the results of the study, the use of traditional methods causes a decrease in the number of students with a low level of knowledge by about 10-12% in both courses, an increase in the number of students with a high level of knowledge by 12-14%, while the number of students with an average level of knowledge remains almost unchanged.

The use of the STEM approach significantly increases the number of students with a high level of knowledge, respectively, by 23% among 1st-year students and by 32% among 2nd-year students; the number of students with a low level of knowledge decreases, but within 10%, which was also recorded during the use of traditional methods. At the same time, there is a decrease in the number of students with an average level of knowledge, respectively by 13% for 1st-year students and 20% for 2nd-year students, but these changes can be explained by a significant increase in the number of students with a high level of knowledge.

Discussion

The results of the study showed that in order for students to assimilate the studied phenomena and concepts, to form convincing ideas in physics, it is necessary to create and work out an appropriate methodology for teaching physics and professionally-oriented disciplines based on STEM technologies, which would improve the level of knowledge and skills, as well as stimulate students to active cognitive-search and independent work during the study of physics in the conditions of STEM-learning development.

The transition to STEM education requires improving the methods of teaching physics, which provides for the following: the use of new methods, techniques, teaching tools that would help solve several methodological problems from the sections of physics; the application and introduction of interesting and important scientific achievements in the educational process in physics (WILLIAMS, 2011), as well as strengthening those aspects that stimulate and activate the independent cognitive activity of students (MARGOT; KETTLER, 2019).

The analysis of scientific works on the problem of teaching physics in the context of the development of STEM education allows identifying the following features of the formation of the STEM component in the teaching of physics and in the innovative educational and scientific environment of the technical university:

1) focus on STEM education, especially on personality-oriented training and the widespread introduction of integrated academic disciplines in technical universities. This direction provides for strengthening the independent cognitive and search activity of students and creating conditions in the educational and learning environment for the self-development and self-realization of each student (BROWN *et al.,* 2011; ENGLISH, 2016);

2) achieving an appropriate ratio and combination of the humanitarian and natural-technical components of the university in STEM education, the optimal combination of their theoretical and practical components, which, respectively, concerns teaching physics (BECKER; PARK, 2011; FREEMAN; MARGINSON; TYTLER, 2015; WHITE, 2014);

3) the rapid development and widespread introduction of digital learning technologies that bring physical education to a new higher level, because the introduction of ICT, 3D modeling, robotic kits, game technologies help students to better assimilate knowledge in physics with the allocation of engineering elements of STEM education (FREEMAN *et al.*, 2014; DECOITO, 2016);

4) the different content of the educational material in physics in terms of the volume and complexity of its presentation, taking into account the integrated approach, should attract the attention of methodologists and specialists of pedagogical science to the fact that knowledge in physics is necessary for all students of higher education institutions, taking into account the concept of developing STEM education and popularizing the technical and engineering component, regardless of which profile and program physics were taught (ERDURAN; OZDEM; PARK, 2015; STOHLMANN; MOORE; ROEHRIG, 2012).

At the same time, confirming the inadmissibility of excessive complication of the educational material with theoretical content and mathematical calculations, it is impossible to similarly discard all possible examples of experimental study of such content, because it is the independent cognitive-search and research activity of the student that underlies active cognition, which realizes his/her desire to know the environment and his/her capabilities in the technical field of training.

Along with this, in the methodology of teaching physics, considering STEM-learning technologies, the following is necessary:

- not to exclude the possibility of using those means and educational equipment in physics that have justified themselves and have been tested by educational practice (KNEZEK; CHRISTENSEN; TYLER-WOOD, 2011); new teaching tools should complement the existing ones and provide opportunities to expand their functions following the new paradigm of education, in which the student is considered as an active subject, the final result of the educational process largely depends on the conscious educational activity (PETERS-BURTON *et al.*, 2014);

- to provide for an increase in the level of independent cognitive-search activity of students at different stages of the formation of physical knowledge, which can be provided by the created sets of equipment, where all the elements and components are coordinated with each other, meet ergonomic requirements, allow getting good results and achieving an appropriate level of physical education (HERNANDEZ *et al.,* 2014; TÜRK; KALAYC; YAMAK, 2018);

- to provide an opportunity to form students' ability to use modern means of digital equipment, ICT and computer technology, orienting them to further use of information tools both in educational activities and in the future professional sphere (LI, 2018; BASHAM; ISRAEL; MAYNARD, 2010);

- to focus on the development of multifunctional physics teaching tools, which should be aimed at the implementation of intrasubject and intersubject relations and the integration of the content of the disciplines of the natural science cycle in the context of the development of STEM education (MALTESE *et al.*, 2015; WANG *et al.*, 2011);

- the created educational set of teaching tools and its methodological support should form an effective educational STEM environment in which both the teacher's activity and the student's work in the process of studying physics are equally effective (ERDOGAN *et al.*, 2016; DECOITO, 2016);

- taking into account the peculiarities of the organization of independent work and the specifics of performing physical research, sets of equipment in physics should be designed for independent work of students, form the ability to adjust physical parameters, anticipate the expected result, independently experiment, perform various measurements and calculations, evaluate physical phenomena, as well as generalize the results obtained (LI; SCHOENFELD, 2019; SHEFFIELDA *et al.*, 2018);

- the system of educational physical experiments in combination with the means of experimentation in physics should be oriented to a modern technological base, meet modern psychological and pedagogical, sanitary, and ergonomic requirements (MOORE; SMITH, 2014). Therewith, it should be assumed that these requirements are not unchanged, they are being improved, and they are in constant development as a separate industry.

Conclusion

The introduction of the STEM training system in technical universities will contribute to the modernization of the system of psychological, pedagogical, methodological, practical training of future applicants for higher education on the principles of STEM education; the establishment of the production of educational STEM equipment and didactic means of STEM teaching physics; the application of the STEM approach to the educational process, which involves personal development aimed at active and constructive entry into modern innovative processes and achieving a high level of self-realization in the study of physical and technical disciplines.

It is experimentally proved that the use of the STEM approach significantly improves the level of assimilation of physical concepts in comparison with traditional teaching methods. Greater efficiency was demonstrated when using the STEM approach for 2nd-year students compared to 1st-year students. When using the STEM approach, the number of students with a high level of mastering concepts increases significantly, while the number of students with a low level decreases, which proves the effectiveness of using the STEM approach for the formation of high-level knowledge and skills. The results obtained indicate that the use of the STEM approach contributes to the development of creativity and creative abilities of students.

We see the prospect of further research in establishing exactly how the use of the STEM approach contributes to the development of creativity and creative abilities of students.

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