Elements of STEM education as a mechanism of compensation for educational losses in distance learning of physics under martial law

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Abstract

The article is devoted to the topical issue of using elements of STEM education as an effective tool to compensate for the educational losses of students in the study of physics caused by the transition to distance learning under martial law. The study analyses the impact of distance learning on the quality of students' acquisition of physical knowledge and skills. The article presents a theoretical overview of the concept of STEM education and its potential for developing critical thinking, creativity and problem-solving skills of students. Based on the analysis of scientific literature and their own experience, the authors develop a model for integrating STEM education elements into the process of distance learning in physics. The empirical part of the study includes a description of an experiment involving students of different age groups. As part of the experiment, educational materials and tasks combining knowledge of physics, mathematics, technology and engineering were developed and tested. Particular attention was paid to the development of methodological solutions for the implementation of distance learning in physics, including the use of virtual laboratories, simulators, interactive platforms and digital tools. The effectiveness of the proposed model was evaluated through a comparative analysis of the learning outcomes of students enrolled in both a traditional distance learning programme and a programme incorporating STEM education elements. The results of the experiment confirm the effectiveness of the use of STEM education elements: the proportion of students with low results decreased (from 25% to 16%), and the proportion of students with sufficient and high levels increased (from 41% to 48%). The analysis of the study results demonstrates that the introduction of STEM education elements in the distance learning of physics contributes to increasing students' motivation to learn; developing their critical and creative skills; deeper understanding of physical phenomena and laws; and developing the ability to apply the acquired knowledge to solve real problems. The authors of the article conclude that the integration of STEM education elements into the process of distance learning in physics is an effective way to compensate for the educational losses of students under martial law. The educational materials and methodological recommendations proposed by the authors can be used by physics teachers to organise effective distance learning.

Keywords

STEM education, distance learning, compensation for educational losses, physics education, project, IT, motivation, martial law education

1. Introduction

The modern educational system of Ukraine is in a unique transformation process caused by a full-scale war, which puts forward fundamentally new requirements for the organisation of the educational process. Distance learning has become not only a temporary solution, but a strategic necessity to ensure the continuity of education [1]. Martial law has dramatically changed the paradigm of the educational process, especially in regions directly adjacent to the war zone. Kherson region, as one of the epicentres

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of educational challenges, demonstrates the extraordinary resilience of the education system and its ability to adapt to extreme conditions.

Distance learning under martial law solves many of the challenges faced by education in Ukraine. At the same time, distance learning requires the joint efforts of parents, students and teachers to achieve the required learning outcomes, as well as support from the state.

The prolonged absence of a stable educational process, constant psychological stress, and lack of access to laboratory equipment and practical training have led to significant educational losses. One of the most affected fields of knowledge was physics, where practical training and laboratory work play a crucial role. Physics is a science that requires a deep understanding of abstract concepts and practical application of knowledge. The lack of opportunities to conduct experiments, model physical phenomena and receive instant feedback from the teacher has made the learning process difficult. Students, especially those who study independently or have limited access to the Internet, have significant difficulties in learning physics.

To overcome these problems, it is necessary to develop innovative approaches to teaching physics that would compensate for educational losses, increase motivation and stimulate students' cognitive activity. One of the promising areas is the integration of STEM education elements into the distance learning process.

STEM education, which combines science, technology, engineering and mathematics, makes it possible to create learning materials that are not only informative but also interesting and practically oriented. The use of STEM approaches in distance learning in physics under martial law allows:

- combine theory with practice: through projects, experiments and modelling, students can apply their knowledge in practice, which contributes to a better understanding of physical phenomena;
- develop critical thinking: STEM tasks are aimed at analysing information, formulating hypotheses and finding solutions, which develops important skills for life;
- increase motivation: interactive tasks, teamwork and the opportunity to see the results of their work make learning more interesting and exciting;
- prepare students for the challenges of the modern world: STEM education develops the skills necessary for successful work in science, technology and engineering and allows for psychological support through cognitive activities.

Despite the obvious advantages of STEM education, its integration into distance learning in physics under martial law remains an insufficiently researched issue. There is a need to develop effective methodologies and tools that would maximise the potential of STEM approaches to compensate for students' educational losses.

2. Literature review

Theoretical and practical aspects of the organisation of the educational process under martial law in Ukraine are considered in the works of many contemporary Ukrainian researchers and educators. An important contribution to the study of this issue was made by: Topuzov, Holovko, Lokshyna, Trubacheva, who studied the peculiarities of distance learning and its adaptation to martial law; analysed the psychological and pedagogical aspects of organising the educational process in crisis conditions; considered systemic approaches to the transformation of education in times of war, issues of ensuring the quality of education and organising a safe educational environment; and focused on the development of digital competence of teachers and students in distance learning during the war.

The main areas of research of these and other scientists are:

- providing psychological support to participants in the educational process;
- organisation of the educational process in conditions of air raids;
- adaptation of curricula to distance and blended learning formats;

- development of teaching methods in conditions of limited access to educational infrastructure;
- creation of a safe educational environment;
- peculiarities of organising the educational process for internally displaced persons;
- use of digital technologies and platforms to ensure continuity of learning.

These studies are of great practical importance, as they help educators adapt the educational process to the difficult conditions of martial law and ensure the proper quality of education despite the existing challenges.

The Ministry of Education and Science of Ukraine determines that the educational process should be focused on creating safe conditions for students and teachers. This implies the use of various forms of education, including distance, blended and face-to-face, depending on the situation in the region.

Scientists attach great importance to identifying key issues of security, psychological support for participants in the educational process, access to distance learning and the reopening of educational institutions, as well as ways to improve distance learning and management of the educational process in extreme conditions [2].

The conditions for ensuring the continuity of the educational process during the war, the readiness of educational systems to provide distance learning opportunities, in particular, the introduction of IT innovations, are explored in the article [3]. The author reveals the crucial role of digital technologies and educational IT infrastructure in ensuring the continuity of the educational process in difficult social circumstances.

The features of blended and distance learning in modern conditions (in particular, under martial law) are studied in [4].

An analysis of the experience of distance learning under martial law [5] showed that, unlike the experience of the COVID-19 pandemic, the main problems are not related to technical aspects, but to organisational difficulties in adapting to new realities.

In December 2022-January 2023, the State Education Quality Service of Ukraine, with the support of the 'Maintaining Access to School Education' initiative implemented by the Support to Ukraine's Government Reforms (SURGe) project, conducted a study of the quality of the educational process in wartime, identified key factors that lead to losses in student learning outcomes and, consequently, in the quality of education, and developed recommendations for public authorities, communities, and schools themselves to overcome these losses [6].

International organisations deal with the issues of compensation for educational losses, having accumulated considerable experience in overcoming the consequences of various crises and emergencies:

- UNESCO is actively developing recommendations and programmes to support education in crisis situations, focusing on ensuring continuity of education and bridging educational gaps. The organisation provides methodological support and coordinates international efforts to restore education systems [7, 8].
- The World Bank implements financial support programmes for education systems in affected countries and develops compensatory education strategies [9, 10].
- UNICEF implements projects to restore access to education for children in conflict and emergency zones, providing both logistical support and the development of special curricula [11, 12].

This experience is particularly valuable for Ukraine, which is currently working to overcome the educational losses caused by military aggression.

A thorough study of the diagnosis and compensation of educational losses as a comprehensive indicator of the educational system is conducted in [13]. It is emphasised that educational losses have a cumulative effect and increase in proportion to the duration of the cessation of functioning of educational institutions. The authors identify the main factors that cause the loss of education under martial law and are related to the lack of access to educational services due to the security situation, the destruction of educational infrastructure, the forced displacement of participants in the educational process and the lack of technical means of distance learning.

The problems of overcoming educational losses under martial law are highlighted in [14]. Ways to solve this problem are proposed through the formation of students' learning competence by humanising education, increasing motivation and introducing effective educational technologies.

In the context of martial law, the socio-psychological adaptation of students is of particular importance. The Guidelines for the Development of STEM Education in General Secondary and Out-of-School Education Institutions in the Academic Year 2023/2024 state that it is the STEM-oriented approach to education that makes it possible to ensure full social and psychological adaptation, specific educational needs, equal access to education and create the necessary conditions for the development of children's abilities [15].

The study by Hrynevych, Morze, and Boyko is devoted to the justification of the need to introduce science education in secondary school in the context of digital transformation. The authors presented an overview of effective innovative pedagogical technologies for the dissemination of scientific thinking and the formation of STEAM competencies [16].

The article [17] presents the experience of implementing educational projects in the context of the transformation of education in Ukraine caused by the war. The authors note that online educational projects based on a STEM-oriented approach, such as the project 'Interesting Science Online', are aimed at overcoming educational challenges and compensating for educational losses by integrating formal and non-formal education in emergency situations.

3. The aim of research

In the current conditions of war in Ukraine, when traditional teaching methods are experiencing significant difficulties, the introduction of STEM education is becoming an important tool to compensate for educational losses. The STEM approach allows for the integration of different subjects and the development of critical thinking, which is especially relevant in the context of distance learning.

Object of research: the process of distance learning of physics in general secondary education institutions under martial law.

Subject of the study: elements of STEM education as a means of compensating for educational losses in distance learning of physics under martial law.

The purpose of the study is to substantiate the effectiveness of using STEM education elements to compensate for educational losses in physics during distance learning under martial law.

Objectives of the study:

- to analyse the current state of the problem of educational losses in distance learning of physics under martial law;
- to determine the features and potential of STEM education elements to compensate for educational losses in the study of physics;
- to develop a model for introducing STEM education elements into distance learning in physics to compensate for educational losses;
- to experimentally test the effectiveness of the proposed model of using STEM education elements to compensate for educational losses;
- to develop practical recommendations for the implementation of STEM education elements in distance learning of physics under martial law, to summarise the results and formulate conclusions.

4. The current state of the problem of educational losses under martial law

The problem of educational losses in the context of martial law and distance learning is becoming particularly acute. Traditionally, researchers have focused on educational losses, which is understandable given their measurability and potential consequences.

Learning losses are defined as any loss of knowledge, skills, abilities and/or slowing or interruption of academic progress due to pauses in a particular student's learning that occur as a result of prolonged absences, ineffective teaching, significant unplanned interruptions in learning related to social crises, wars, natural disasters, etc.

Experts of the CEDOS Analytical Centre define educational losses as gaps in knowledge and skills that arise in students during the educational process compared to the state standard of secondary education and expected results of educational achievements [18].

However, based on the understanding of education as a unity of learning, upbringing, development and socialisation of the individual, educational losses should be considered in three interrelated dimensions:

- learning losses (in the sense of loss of knowledge, skills, attitudes, etc);
- educational losses;
- slowing down the pace of personal development [19].

This comprehensive approach will allow us to better understand the problem of educational losses and develop effective strategies to compensate for them.

The analysis of educational losses is carried out using different approaches: international monitoring studies, national standardised tests, calculation of lost learning time and surveys of participants in the educational process. These methods complement each other, and their list is not exhaustive [18].

The Programme for International Student Assessment (PISA), an international study of the quality of education launched by the Organisation for Economic Co-operation and Development (OECD), measures 3 types of literacy:

- reading;
- mathematics;
- natural science.

The problem of educational losses is significantly exacerbated under martial law. Thus, the results of the PISA 2022 study indicate not only a lower level of mathematical, reading and science literacy among Ukrainian students than the OECD average, but also the extent of educational losses compared to 2018. According to PISA standards, they are equivalent to half a year of study in science, one year of study in mathematics, and two years of study in reading (figure 1) [20].

Figure 1: Trends in average performance in mathematics, reading, and science in Ukraine and OECD countries between the 2018 and 2022 PISA cycles.

Among the long-term negative impacts caused by the war, UNESCO identifies the following

- physical danger to students; damage to educational infrastructure; absenteeism;
- increased violence in educational institutions;

- reduced motivation to learn and mental health of students;
- loss of students and teachers as a result of hostilities;
- illegal persecution and detention of teachers and students;
- forced outflow of qualified teachers and managers abroad;
- insufficient supply of teaching staff to educational institutions;
- violation of the established mechanisms of training and retraining of pedagogical staff [21, 22].

The factors that complicate distance learning in physics under martial law include:

- limited access to equipment and laboratory work - the inability to conduct experiments due to the destruction of laboratories, lack of equipment and consumables;
- interruptions in power supply and communication;
- unequal access to quality education - deterioration of conditions for studying physics among students in frontline areas, temporarily displaced persons and children studying abroad.

These factors have a significant impact on the quality of physical education and require finding effective solutions to overcome them.

According to the Ukrainian Institute for Educational Development, educational losses can be overcome through such activities as catching up, combining, and adjusting students' self-education in different life situations. UDI methodologists have collected useful materials that will help teachers identify and make up for the educational losses of students. To directly determine the level of educational losses, diagnostic tests have been developed and are available on the All-Ukrainian School Online (ASO) web platform [23].

5. Features and potential of STEM education elements to compensate for educational losses in physics learning

STEM education modernises the methodological foundations, content, and scope of the teaching material of the natural and mathematical cycle, the technologicalisation of learning, and forms learning competences of a qualitatively new level. Integrated thinking intersects with an interdisciplinary approach that combines situational learning, engineering design, scientific research, technological literacy, and mathematical thinking [24].

STEM education is an integrated approach to that combines science, technology, engineering and mathematics. Its goal is not just to impart knowledge, but to teach students how to apply it in practice, develop critical thinking, creativity and problem-solving skills.

The effectiveness of STEM education in the context of compensating for educational losses is based on the following key elements

- Interdisciplinary approach. The implementation of integrated lessons and projects helps students to develop a holistic view of the interconnectedness of different STEM disciplines, showing how different sciences work together, in particular mechanics involves the use of mathematical models to describe and analyse physical phenomena; the study of electricity uses programming methods to model electrical circuits; the study of light involves understanding chemical processes and biological aspects of vision.
- Development of engineering thinking. Designing, constructing and testing models of physical phenomena makes learning more exciting and contributes to a deeper understanding of the material by filling in gaps in knowledge.
- Use of technology. The use of modern technologies, such as augmented reality, virtual laboratories, interactive simulations, online collaboration platforms, helps to overcome learning losses, allows complex processes to be visualised and experiments to be carried out in a safe and controlled virtual environment. virtual environment, which helps students to understand the material better, fill in gaps in their knowledge and increase their interest in learning.

- Practical application of knowledge. Carrying out practical tasks, experiments and projects helps students to gain a deeper understanding of physical laws and phenomena. In the context of distance learning, the use of virtual laboratories, simulations and online experiments allows for a practical component of learning, compensating for the lack of physical contact with equipment and facilitating the recovery of lost knowledge.
- The development of critical thinking and problem solving skills through STEM education helps to overcome educational losses, as students are not limited to memorising facts, but learn to analyse information, assess its reliability and draw and make informed conclusions. The ability to ask questions, search for information and find solutions allows students to regain lost knowledge and develop self-learning skills.

Virtual laboratories and simulations are an important element of the modern educational process, as they allow overcoming the limitations of distance learning, providing a differentiated approach and increasing student motivation [25]. These tools promote deeper learning through interactive modelling of real processes and phenomena, which is especially relevant for teaching natural sciences, including physics [26].

Among the popular resources that are actively used by teachers to illustrate theoretical concepts and develop practical skills are the PhET (table 1), AR Book and Labster platforms [27, 28]. They provide interactivity, visibility and the ability to conduct safe experiments [29].

Micro:bit kits are used to develop students' technical and programming skills, as well as to integrate STEM components into physics teaching. Thus, the use of virtual laboratories and simulators not only compensates for the shortcomings of distance learning, but also creates conditions for the formation of key competencies of the XXI century.

PhET simulations are an effective means of forming a conceptual understanding of fundamental concepts, phenomena and processes, especially in distance learning. Their use in combination with a home experiment helps to develop research skills, increase motivation and ensure a deeper understanding of the learning material.

In the context of distance learning in physics, the use of demonstrations, simulations and digital laboratories to visualise and explain the principles of laboratory equipment is of particular relevance. The lack of direct access to physical experiments makes it impossible to conduct traditional laboratory work, which can have a negative impact on the development of students' practical skills. Digital tools partially compensate for this shortcoming by providing interactive modelling of physical phenomena, real-time investigation of experimental parameters, and bringing the learning experience closer to real laboratory conditions (table 2). This contributes not only to a better assimilation of theoretical material but also to the development of students' research competencies in a remote format based on STEM education.

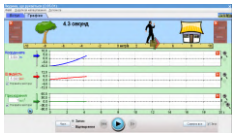
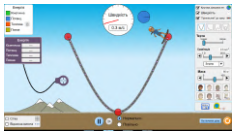
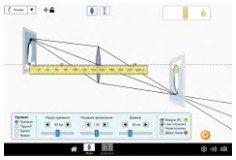
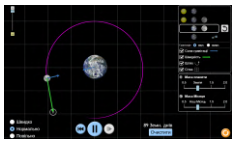
Among the teaching methods in STEM education, a special place is occupied by project-based learning and experimental activities [24].

Students' motivation to study physics is significantly increased by performing home experiments that do not require sophisticated equipment. For example, a study of rotational motion using a mathematical pendulum that students can perform with their families. Simple experiments, such as demonstrating diffusion using a glass of cold and hot water and paints, are appropriate. To explain the concepts of density and Archimedes' force, a potato experiment can be used, which is easily accessible at home. These experiments not only illustrate physical processes, but also create problematic situations that stimulate students' cognitive interest, promote the development of research skills, and encourage further research (figure 2).

An important component of STEM projects is the presentation of the results. During project activities, students are encouraged not only to complete tasks, but also to improve them and be creative. One of the modern ways to demonstrate the results of work is to create short videos and infographics. This helps to build self-presentation skills and develop creativity.

Digitalisation of the educational process is the basic foundation of STEM education, which adds differentiation, individualisation, and mobility to learning. Digitalisation makes it possible to intensify

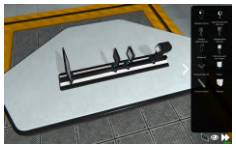
Table 1
PhET simulations for teaching physics.

Topic	Simulation name	Description	Screenshot
Mechanical motion	The Moving Man	explains the basic principles of mechanical motion, explores its characteristics, and learns how to create and analyse motion graphs	
Mechanical movement. Laws of energy conservation	Skateboard park	studying the principles of mechanical energy conservation, conducting virtual laboratory work on the analysis of kinetic and potential energy, demonstrating energy saving processes in dynamic systems	
Optics	Geometric optics	study of image formation in lenses and mirrors, analysis of optical phenomena and training in the calculation and construction of light ray paths in various optical systems	
Movement in a circle. Gravity	Gravity and Orbits	study of the movement of bodies along circular trajectories under the influence of gravity, study of the principles of gravitational interaction, analysis of factors affecting the orbits of planets and satellites, formation of interest in astronomy	
Atomic physics half-life	Radioactive dating game	learning the principle of radioactive decay and half-life, consolidating skills in analysing the isotopic composition of samples, demonstrating the practical application of radioactive dating in archaeology and geology	

the educational process, increase the speed and quality of perception, understanding and assimilation of physics learning material.

Mozaik Education 3D scenes are used to introduce students to the operation of complex mechanisms in depth, allowing them to explore the principles of functioning of various mechanisms (figure 3). The visualisation of processes contributes to a better understanding of the material, increases motivation to

Table 2
Programmes to support laboratory work, research and experimentation.

Topic	Simulation/programme	Description	Screenshot
Laboratory work in the course of physics	Interactive support for textbooks. Ranok Publishing House	Videos are made using professional laboratory equipment	
Experiments	PHYSICS LAB	Virtual 3D simulator of laboratory and practical work in physics	

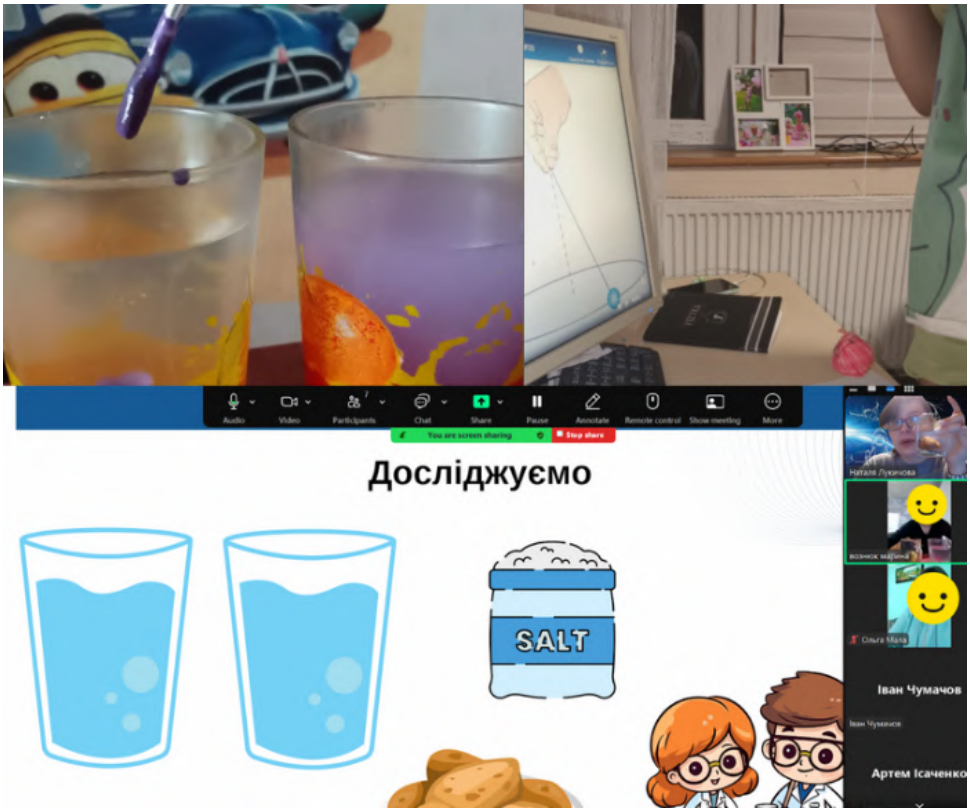


Figure 2: Examples of STEM research projects.

learn and demonstrates the practical relevance of the knowledge gained.

The use of IT in the classroom expands opportunities for student interaction and motivation through interactive presentations, online whiteboards, simulations, exercises and quizzes. The Quizizz service provides tools for creating interactive lessons, tests and quizzes, and automates routine processes using artificial intelligence, allowing teachers to focus on creative work. This tool supports gamification of learning and stimulates students' independent work.

AI-powered assistants help teachers develop materials, generate ideas, and adapt tasks to the level of students, as well as create emotionally charged materials such as songs or fairy tales. However, for AI to be effective in education, human-machine collaboration is important, including teacher creativity, critical evaluation of results, and combination with media literacy training.

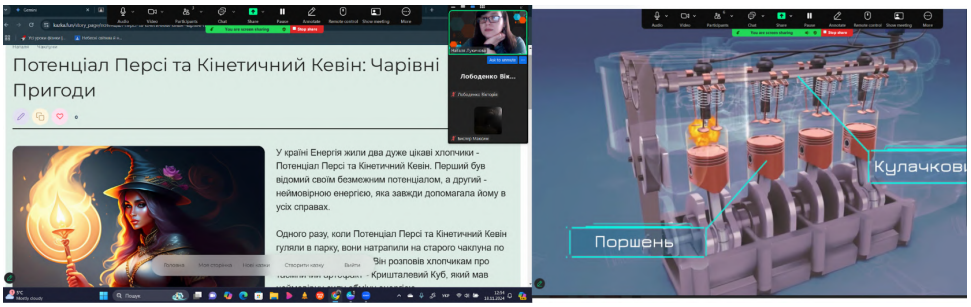


Figure 3: Examples of the use of IT in physics lessons.

6. A model for introducing STEM education elements into distance learning in physics

The STEM approach in education is a response to social requirements and the main tasks of the Recovery Plan of Ukraine (compensation for educational losses, strengthening the integration of science and innovation in the educational process, etc).

The concept for the development of science and mathematics education (STEM education) in Ukraine [30], which is to be implemented by 2027, states that in order to actively involve students in research and development activities, it is necessary to introduce new methods and forms of organising the educational process.

Due to the peculiarities of the distance learning format of physics, the model of STEM education implementation in general secondary education institutions developed in [31] has been amended accordingly (figure 4).

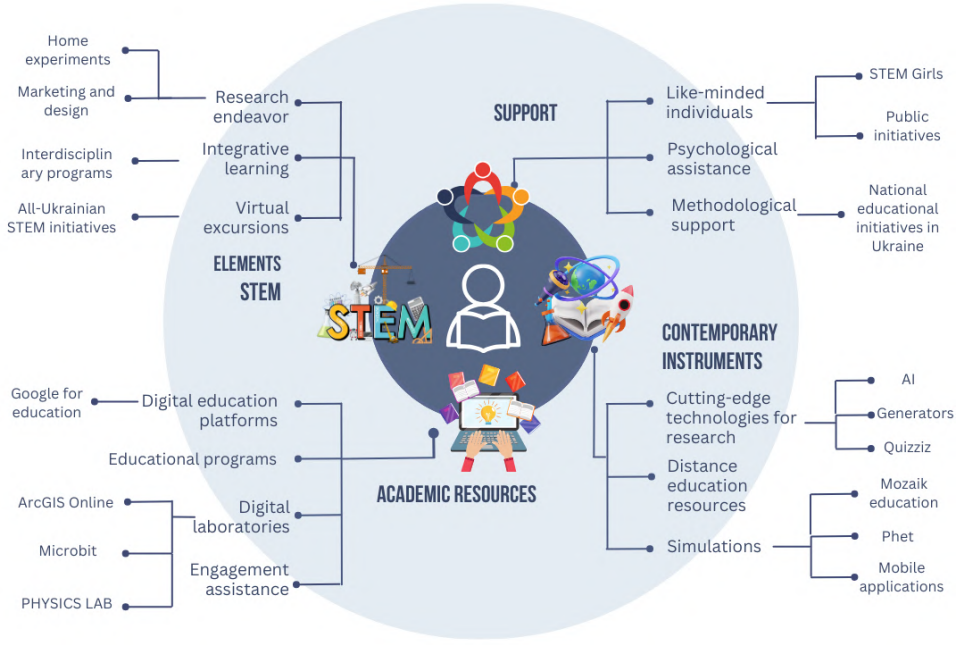


Figure 4: Model for implementing STEM education elements in distance learning in physics.

Taking into account the specifics of distance learning in physics, the model provides a variety of support for students and teachers, including psychological assistance, methodological support and community organisation. The use of modern tools, such as Google for Education, digital platforms, laboratories, simulators, and mobile applications, is an important component of the model. Students

have access to a variety of academic resources, including educational programmes, digital labs and interactive platforms. Students are engaged in learning through interesting tasks, experiments, and projects, and participation in STEM initiatives helps to develop interest in STEM education. The model also includes integrative learning, virtual field trips, and research activities.

Key elements of the model:

- Elements. The STEM elements include science, technology, engineering, and mathematics, which are the basis for an integrated approach to learning.
- Support. A variety of support is provided to students and teachers, including psychological help, methodological support, and a community of like-minded people.
- Modern tools. The use of modern technologies and tools such as Google for Education, digital platforms, laboratories, simulations and mobile applications.
- Academic resources. Access to a variety of academic resources, including educational programmes, digital laboratories, simulations and interactive platforms such as Mozaik education and Phet.

Active involvement of students in learning is ensured through interesting tasks, experiments and projects. Participation in all-Ukrainian and national STEM initiatives, which promotes interest in STEM education.

The model provides for a comprehensive integration of various resources and approaches to ensure effective teaching of physics in distance learning, contributing to the development of students' STEM competencies.

7. Experimental testing of the effectiveness of the model of using STEM education elements to compensate for educational losses

The study of the effectiveness of the model of using STEM education elements to compensate for educational losses was conducted on the basis of the Beryslav Academic Lyceum of the Beryslav City Council (Ukraine) under the guidance of the Kherson Academy of Continuing Education of the Kherson Regional Council.

The experiment involved 280 students of grades 7-11 studying physics in distance learning.

The research hypothesis: The introduction of STEM education elements in distance learning in physics helps to compensate for educational losses in martial law, as well as to increase the effectiveness of learning, develop critical thinking and creative abilities of students.

During the 2022-2023 academic year, the first stage of the experiment was conducted, in which a control group of students (280 students) was engaged in making up for educational losses caused by external factors using traditional teaching methods. This stage was aimed at establishing a baseline for the effectiveness of standard educational practices in bridging learning gaps.

In the second stage of the experiment, which took place in the academic year 2023-2024, an experimental group of students (280 students) used a STEM approach to make up for educational losses. This approach involves the integration of natural sciences, technology, engineering and mathematics, which allows students to develop critical thinking, problem-solving skills and practical application of knowledge. Comparing the results of the two stages will allow us to assess the effectiveness of the STEM approach compared to traditional methods in the context of overcoming educational losses.

In the control group (academic year 2022-2023), the catch-up of educational losses was carried out using traditional teaching methods, including lectures, textbooks, watching videos, teacher demonstrations, solving problems and conducting tests. The main emphasis was placed on reproductive tasks aimed at reproducing theoretical material. This approach implies minimal student activity in the learning process, focusing on passive learning.

The experimental group (academic year 2023-2024) used a STEM approach that integrates science, technology, engineering, and mathematics through practical projects. The educational process was organised around research and project tasks that promoted the development of interdisciplinary connections and the active use of information technology. This approach stimulated active participation of

students, development of critical thinking and practical application of knowledge, which contributed to a deeper understanding of the material and the formation of skills necessary for successful learning.

Since 2023, the teaching of physics has focused on the use of STEM education elements and the use of IT technologies in distance learning. Additional mechanisms have been introduced to compensate for educational losses, namely: development of individual and group compensatory training programmes; psychological support for participants in the educational process; creation of additional educational opportunities (summer schools, electives); adaptation of curricula and teaching methods; and professional development of teachers to work in crisis conditions.

In order to overcome educational losses by introducing elements of STEM education, considerable attention is paid to the material and technical support of participants in the educational process. For example, under the programme, the Olena Zelenska Foundation, together with the Ministry of Education and Science and the Ministry of Digital Transformation of Ukraine, received and transferred laptops and tablets to meet the educational needs of students and teachers.

One of the effective mechanisms for overcoming educational losses was the creation of an educational hub, a secure educational environment that combines cloud services for storing didactic materials and ensuring communication between all participants in the educational process.

In 2023-2024, elements of STEM education were systematically introduced into distance learning in Physics, namely: an interdisciplinary approach, development of engineering thinking, use of technology, practical application of knowledge, development of critical thinking and problem solving skills. An example of the integration of STEM education elements in the planning of the section "Electrical Phenomena. Electric current" in grade 8 is shown in table 3.

The following compensatory measures were provided for students who were subjected to regular power outages and communication interruptions: asynchronous access to materials, flexible deadlines for submitting assignments, alternative forms of participation, and recordings of experiments and demonstrations.

Students presented their project results using shared whiteboards (figure 5)

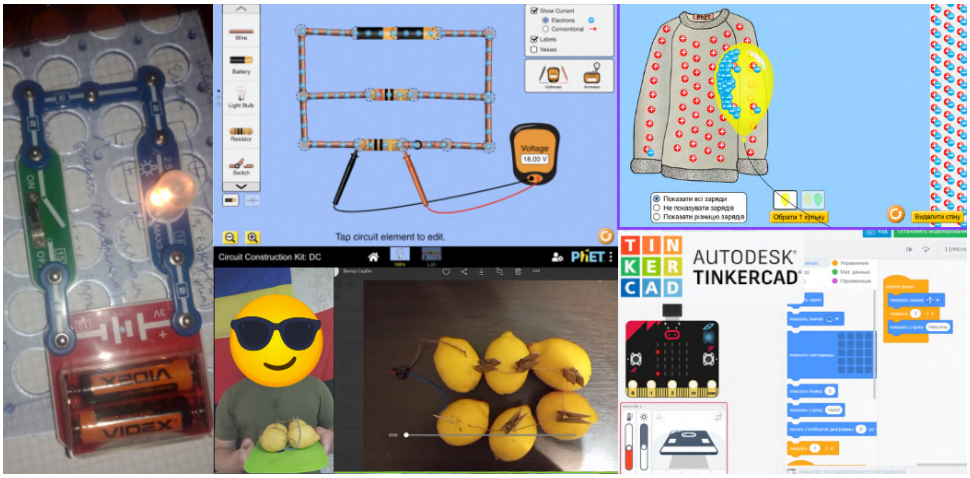


Figure 5: Shared board with the results of students' projects.

An important impact on increasing students' motivation to study physics is made by: organising online seminars, webinars and workshops with scientists, engineers and inventors, which address problematic issues and highlight interesting solutions; creating communities for the exchange of ideas, mutual assistance and cooperation ("STEM Girls"); celebrating holidays ("Girls in ICT Day", "Women in Science Day"); joining international, national and regional initiatives, competitions, festivals and Olympiads.

Key conditions of the experiment:

- All participants of the experiment (control and experimental groups) were taught by the same teachers, which excluded the influence of the teacher as a factor.

Table 3
Application of STEM elements in the study of the section "Electrical phenomena. Electric current" section of the 8th grade physics course.

Lesson topic	Traditional approach: activities	STEM elements that complement traditional activities
Electrical phenomena. Electrification of bodies. Electric charge. Two types of electric charge.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	Investigation of the phenomenon of electrification with the materials available: balloons, combs, pens, salt, pepper. Use of simulations "Balloons and static electricity"; "John Travoltage". Realisation of the project "Creation of a device that reacts to electrified bodies".
Interaction of charged bodies. Coulomb's law. The law of conservation of electric charge.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	Using the Coulomb's Law simulation. Create a 3D model of the electric field around charged bodies.
Electric field.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	Modelling electric fields of various configurations using the Charges and Fields simulation. A project to create a device that displays the strength of an electric field using LEDs (design and programming in Tinkercad).
Electric current. The effect of electric current. Conductors, semiconductors, dielectrics.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	Investigation of the dependencies using "Direct Current" simulation. A project to create a device to automatically adjust the brightness of an LED depending on the illumination.
Sources of electric current.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	A project to create your own current source (for example, from a lemon or potato).
Problem solving.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	Use of online platforms, interactive physics exercises. Games to consolidate the material.
Current strength. The unit of electrical current. Amperemeter.	Working with the textbook, watching videos, teacher demonstrations, solving problems.	Research "Measuring the current strength in different parts of an electric circuit using an ammeter" using a virtual laboratory. A project to create an ammeter using microcontrollers (whenever possible).

- The physics curriculum was the same in each year, the difference was in the teaching methods.
- The same outcome assessment tools were used (diagnostics, tests, projects, surveys, observations, monitoring of academic achievement and analysis of participation in extracurricular activities).

The assessment of the level of knowledge acquisition was based on five key criteria.

1. Understanding of physical phenomena – involves determining the ability of students to identify, explain and interpret physical processes, their essence, patterns and principles of functioning, as well as to establish cause and effect relationships between different physical phenomena.
2. The ability to apply knowledge in practical situations – determines the ability of students to transform theoretical knowledge into practice, solve typical and non-standard problems, find

optimal solutions in simulated real-life situations and demonstrate functional literacy in the use of physical knowledge.

3. Research skills – assesses the formation of the ability to formulate hypotheses, plan and conduct experiments, collect data, analyse and interpret them, draw reasonable conclusions based on empirical research, and use scientific methods of knowledge.
4. Creativity in solving problems – determines the ability of students to generate original ideas, use non-standard approaches to solving problem situations, show flexibility of thinking, develop innovative methods and find alternative ways to solve problems.
5. Level of autonomy – assesses the degree of autonomy of students in learning activities, their ability to independently plan, organise and regulate their own learning process, make independent decisions, take responsibility for the results of their activities and work productively both individually and in a collaborative format.

Students' knowledge was assessed using a comprehensive five-level scale: unsatisfactory, elementary, intermediate, sufficient and high levels. A detailed description of each level by all criteria is presented in table 4.

Data collection tools included: diagnostics, observation, monitoring of academic achievement and analysis of participation in extracurricular activities (competitions, online competitions). The research procedure involved diagnostic work at the beginning and end of the school year, as well as summarising and analysing quarterly monitoring of academic achievement (semester and annual assessments).

To evaluate the effectiveness of the STEM approach in the process of making up for educational losses, a comparative analysis of the levels of knowledge acquisition of students in the control (2022-2023) and experimental (2023-2024) groups was conducted. The results indicate a significant improvement in the academic achievements of students who studied according to the STEM model. In particular, the proportion of students with unsatisfactory and elementary levels has decreased, while the number of students with sufficient and high levels has increased significantly. Detailed statistics are presented in table 5.

The analysis of the results of the experimental study shows significant differences in the levels of knowledge acquisition between the control and experimental groups. In the control group (academic year 2022-2023), which was taught using traditional methods, the following distribution of knowledge acquisition levels was observed: unsatisfactory level was demonstrated by 4% of students, elementary - 21%, intermediate - 34%, sufficient - 34%, high - only 7% of respondents. This stratification indicates the dominance of average and below average levels of learning when using traditional methods of overcoming educational losses. These results confirm the existing educational losses and are explained by the difficulties of distance learning under martial law: lack of material resources for learning, regular power outages, migration (movement of students abroad and within Ukraine), communication interruptions and a difficult psychological state, and as a result, low motivation to learn.

In contrast, the experimental group (academic year 2023-2024), where elements of the STEM approach were implemented, showed a much more optimistic picture of the distribution of results: the proportion of students with unsatisfactory levels of learning decreased to 2%, with primary - to 14%, with average - to 36%, while the proportion of students with sufficient levels increased to 37%, and with high - to 11%. This indicates the transformation of the distribution towards the dominance of high and sufficient levels, which is 48% of the total number of participants in the experimental group.

A comparative analysis of the results (figure 6) reveals significant differences between the groups: the proportion of students with an unsatisfactory level has halved (from 4% to 2%), with an initial level - decreased by 7 percentage points (from 21% to 14%), while the percentage of students with a sufficient level increased by 3 percentage points (from 34% to 37%), and with a high level - increased by 4 percentage points (from 7% to 11%). There are also positive changes in the level of engagement in learning activities, which is manifested in an increase in the number of participants and winners in subject competitions and Olympiads in physics, including the All-Ukrainian Internet Olympiads on the Na Urok platform. These indicators verify the hypothesis that the STEM approach is more effective in making up for educational losses than traditional teaching methods.

Table 4
Evaluation scale of knowledge levels for each criterion.

Criterion	Unsatisfactory	Initial	Average	Adequate	High
Understanding of physical phenomena	Lack of understanding of basic physical concepts and phenomena, unable to apply them.	Limited understanding, can recall individual concepts but is unable to clearly explain the relationship between them.	Understands basic principles but makes mistakes in application.	Clear understanding of basic physical phenomena, able to explain them with examples.	In-depth understanding of physical phenomena, able to evaluate and draw conclusions analytically.
Ability to apply knowledge in practical situations	Cannot apply theoretical knowledge in practice, unable to solve problems.	Can solve some problems, but with difficulty and without clear logic.	Able to apply knowledge to solve standard problems, makes mistakes in more complex cases.	Solves intermediate-level practical problems without errors, can explain the application of theory to practice.	Solves complex problems, adapting knowledge to non-standard situations.
Research skills	Has no research skills and is unable to formulate hypotheses.	Has basic skills, but often makes mistakes in planning and conducting experiments.	Is able to perform basic research, formulate hypotheses, but makes inaccuracies.	Conducts research with minimal errors, interprets results correctly.	Conducts experiments with clear results, draws reasonable conclusions.
Creativity in solving problems	Does not show creativity, uses standard methods.	Shows minimal creativity, sometimes tries new approaches but fails to get results.	Able to use non-standard methods, but to a limited extent.	Actively seeks out new approaches and demonstrates original ideas.	Shows high creativity, finds innovative solutions, can develop new methods.
Level of independence	Needs constant assistance, cannot perform tasks without support.	Works independently only in the simplest form, often needs additional explanations.	Works independently on most tasks, but needs help in complex cases.	Able to work independently in most situations, rarely asks for help.	Shows high independence, is able to organise his/her work and solve complex problems without assistance.

8. Conclusions and prospects for further research

The results of the study confirm the effectiveness of using elements of STEM education to compensate for the educational losses of students in the distance learning of physics under martial law. The introduction of the STEM approach helps to increase students' motivation, develop their critical and creative skills, and form the ability to apply the acquired knowledge to solve real-world problems.

The results of the pilot study confirm the effectiveness of using STEM education elements in overcoming educational losses compared to traditional teaching methods. The integration of STEM components contributed to a significant reduction in the proportion of students with unsatisfactory and elementary levels (from 25% to 16%) and an increase in the proportion of students who achieved sufficient and high levels (from 41% to 48%). In addition, there was an increase in student engagement in learning

Table 5
Experimental results.

Academic year	Group	Unsatisfactory	Initial	Average	Adequate	High
2022-2023	Control group	4%	21%	34%	34%	7%
2023-2024	Experimental group	2%	14%	36%	37%	11%

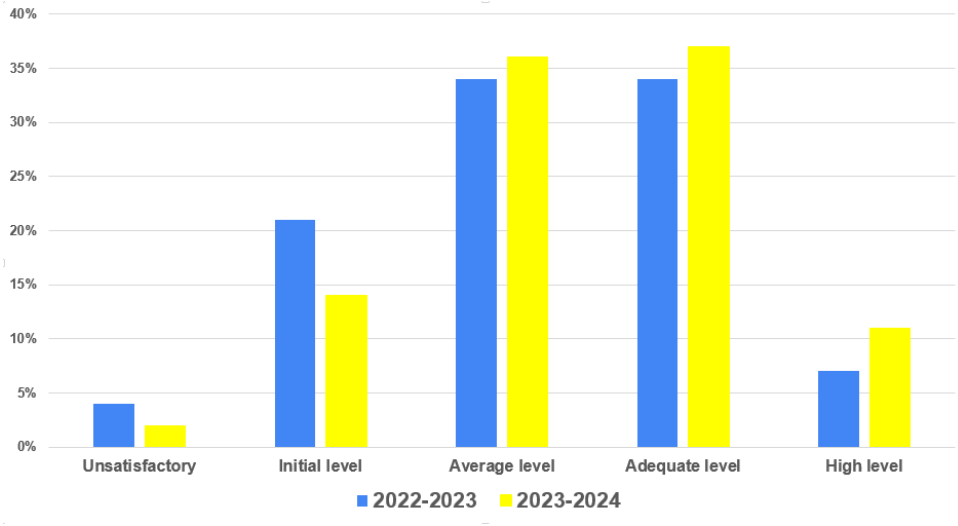


Figure 6: Results of monitoring the level of students' learning achievements in physics in 2022-2024.

activities, which manifested itself in an increase in the number of participants and winners of subject competitions and olympiads. Thus, the use of STEM education elements allows not only to compensate for educational losses, but also to increase students' motivation to learn, develop their research skills and promote the formation of competencies necessary for successful study and further professional activity.

The analysis of the results of the experiment demonstrated a significant improvement in the level of mastery of physical concepts, understanding of physical concepts and laws by students who studied under a programme using STEM elements, compared to traditional distance learning.

An important aspect of the effective implementation of STEM education is the development of high-quality teaching and learning materials, including interactive tasks, virtual laboratories, digital simulations, and interdisciplinary projects. Training of teaching staff capable of effectively using STEM methods in distance learning also plays a key role.

Prospects for further research include expanding the empirical base on the impact of STEM education on the development of students' skills in the long term, analysing the effectiveness of various digital tools in the process of distance learning physics, and developing adaptive curricula focused on the individual needs of students. In addition, it is important to study the possibilities of integrating STEM education with other modern educational approaches, such as problem-based learning and gamification, which will increase student motivation.

Author Contributions

Natalia S. Lukychova – organized and conducted the experiment, collected data, and performed statistical processing and analysis of the results; Nataliia V. Osypova – developed the concept and methodology of the study; Galina S. Yuzbasheva – analyzed the state of development of the research problem and

checked the correctness of the conclusions. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

No new data were created or analysed during this study. Data sharing is not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration on Generative AI

The authors declare that no generative artificial intelligence (AI) tools were used in the writing, editing, data analysis, or any other aspect of this manuscript.

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References

[1] Prydniprovska State Academy of Civil Engineering and Architecture, Collection of materials of the II Forum of the academic community Education in Wartime, 2022. URL: https://pgasa.dp.ua/wp-content/uploads/2022/09/Zbirnyk-materialiv-II-Forumu-akademichnoyi-spilnoty-OSVITA-V-UMOVAH-VIJNY.pdf.

[2] O. Zozulak, N. Bashuryn, Organizational, Legal and Administrative Mechanisms for Ensuring the Educational Process in the Conditions of Martial Law in Ukraine, International Journal of Legal Studies (IJOLS) (2023). doi:10.5604/01.3001.0054.5501.

[3] L. Londar, M. Pietsch, Providing Distance Education During the War: The Experience of Ukraine, Information Technologies and Learning Tools 98 (2023). doi:10.33407/itlt.v98i6.5454.

[4] A. Melnyk, Problems of using elements of distance learning under martial law, Bulletin of Kyiv National Linguistic University. Series "Psychology and Pedagogy" 37 (2023). doi:10.32589/2412-9283.37.2022.272900.

[5] V. Trotsko, I. Chernozubkin, Experience of Using the E-Learning System in Martial Law Conditions, Scientific Notes of the University "KROK" 70 (2023) 100–105. doi:10.31732/2663-2209-2022-70-100-105.

[6] State Quality Service of Education of Ukraine, One third of students did not have regular access to education during the war – study finds, 2023. URL: https://sqe.gov.ua/tretina-uchniv-v-umovakh-viyni-ne-mali-po/.

[7] UNESCO, Recovering lost learning: what can be done quickly and at scale?, 2021. URL: https://unesdoc.unesco.org/ark:/48223/pf0000377841.

[8] Education Ombudsman of Ukraine, Forced Displacement and Compensation for Educational Losses of Children at the Community and Educational Institution Levels, 2023. URL: https://eo.gov.ua/

vymiriuvannia-ta-kompensatsiia-osvitnikh-vtrat-ditey-na-rivni-hromady-ta-zakladu-osvity/2023/01/25/.

[9] World Bank, Education: the consequences of the war in Ukraine, 2024. URL: https://documents1.worldbank.org/curated/en/099631507072239980/pdf/IDU04805ab35047b2049990a0e101c605921c504.pdf.

[10] World Bank, Relief, recovery and sustainable reconstruction, 2023. URL: https://documents1.worldbank.org/curated/en/099547405052230400/pdf/IDU063b2f81900861047a70b5540e3e950f93a8c.pdf.

[11] UNICEF Ukraine, UNICEF Ukraine Humanitarian Situation Report No. 46 (1-30 November 2024), 2024. URL: https://www.unicef.org/ukraine/en/media/49676/file/UNICEF%20Ukraine%20Humanitarian%20Situation%20Report%20No.46%201-30%20November%202024.pdf.pdf, report number 46.

[12] UNICEF Ukraine Country Office, Situation Analysis of Children in Ukraine 2024, Technical Report, UNICEF, New York, 2024. URL: https://www.unicef.org/ukraine/media/49206/file/UNICEF_SitAn_2024_ENG.pdf.pdf.

[13] O. Topuzov, M. Holovko, O. Lokshyna, Educational Losses During Martial Law: Problems of Diagnosis and Compensation, Ukrainian Educational Journal 1 (2023) 5–13. doi:10.32405/2411-1317-2023-1-5-13.

[14] S. Trubacheva, The Development of Educational Competence of Students in the Conditions of Martial Law, Scientific Bulletin of Uzhhorod University. Series: «Pedagogy. Social Work» 53 (2023) 139–142. doi:10.24144/2524-0609.2023.53.139-142.

[15] Institute for the Modernisation of Educational Content, Methodological Recommendations for the Development of STEM Education in General Secondary and Out-of-School Education Institutions in the Academic Year 2023/2024, Website Osvita.ua, 2023. URL: https://osvita.ua/legislation/Ser_osv/89820/, official letter No. 21/08-1242 of 01 August 2023.

[16] L. M. Hrynevych, N. V. Morze, V. P. Vember, M. A. Boiko, The role of digital technologies in the development of the stem education ecosystem, Information Technologies and Learning Tools 83 (2021) 1–25. URL: https://journal.iitta.gov.ua/index.php/itlt/article/view/4461. doi:10.33407/itlt.v83i3.4461.

[17] R. Dinzhos, I. Mankus, L. Nedbaevska, V. Darmosiuk, Educational project "Interesting science online" as a way of compensating educational losses in the conditions of war in Ukraine, Modern Information Technologies and Innovation Methodologies of Education in Professional Training Methodology Theory Experience Problems (2024) 5–13. doi:10.31652/2412-1142-2024-72-5-13.

[18] Y. Nazarenko, I. Verbicky, Educational Losses: Approaches to Measurement and Compensation, 2022. URL: https://cedos.org.ua/wp-content/uploads/zapyska_osvitni-vtraty.pdf.

[19] H. Bychko, V. Tereshchenko, Learning Losses: Essence, Causes, Consequences, and Ways to Overcome, Ukrainian Center for Educational Quality Assessment, 2023. URL: https://testportal.gov.ua/wp-content/uploads/2023/04/Learning-losses_Ukraine.pdf.

[20] U. C. for Educational Quality Assessment, PISA 2022 National Report (Short Version), Technical Report, Ukrainian Center for Educational Quality Assessment, Kyiv, 2023. URL: https://pisa.testportal.gov.ua/wp-content/uploads/2023/12/PISA-2022_Naczionalnyj-zvit_korotkyj.pdf.

[21] O. Lokshina, O. Hlushko, A. Dzhurylo, S. Kravchenko, O. Maksymenko, N. Nikolska, O. Shparyk, Education in the realities of war: guidelines of the international community: a review edition, Pedagogical Thought, Kyiv, 2022. doi:10.32405/978-966-644-614-8-2022-55.

[22] N. Balyk, O. Barna, G. Shmyger, V. Oleksiuk, Model of professional retraining of teachers based on the development of STEM competencies, volume 2104, 2018, p. 318 – 331. URL: https://ceur-ws.org/Vol-2104/paper_157.pdf.

[23] Ukrainian Institute of Educational Development, Tools for Identifying and Addressing Educational Losses, Information and Analytical Materials on the Organization of the Educational Process under Martial Law (2023). URL: https://uied.org.ua/2023/12/11407/.

[24] Institute for Modernization of the Content of Education, Methodological Recommendations for the Implementation of STEM Education in Educational Institutions of Ukraine, 2024. URL: https:

//drive.google.com/file/d/1M7EGKUxciCGup4wn5XogNNpsjlL3kElY/view, iMZO Official Letter No. 21/08-1242, August 12, 2024.
[25] N. Dementievska, O. Sokoliuk, Virtual Laboratory Works in Physics Using Interactive Computer Modeling: A Collection of Educational Materials, ICo NAES of Ukraine, Kyiv, 2022. URL: https://lib.iitta.gov.ua/id/eprint/733495/.
[26] PhET Interactive Simulations, PhET Interactive Simulations, 2024. URL: https://phet.colorado.edu/uk/.
[27] AR Book, AR Book - Augmented Reality for Education, 2024. URL: https://arbook.info/.
[28] Labster: Virtual Labs for Universities and High Schools, 2024. URL: https://labster.com/.
[29] O. Y. Romanyshyna, N. R. Balyk, V. Y. Habrusiev, H. R. Henseruk, O. Y. Karabin, M. Karpinskyi, S. V. Martyniuk, H. M. Skaskiv (Eds.), Modern Digital Technologies and Innovative Teaching Methods: Experience, Trends, Prospects, Ternopil Volodymyr Hnatiuk National Pedagogical University, 2023. URL: https://lib.iitta.gov.ua/id/eprint/735000/.
[30] Educational Project Na Urok, Education of the New Generation: TOP-5 AI Opportunities, Na Urok (2024). URL: https://naurok.com.ua/post/osvita-novogo-pokolinnya-top-5-mozhlivostey-shi.
[31] N. Lukychova, N. Osypova, G. Yuzbasheva, ICT and current trends as a path to STEM education: implementation and prospects, in: CTE Workshop Proceedings, volume 9, 2022, pp. 39–55. doi:10.55056/cte.100.