Educational direction of STEM in the system of realization of blended teaching of physics

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Abstract. Today's requirements for the training of specialists encourage the modernization of education through the introduction of new educational technologies, in particular the introduction of STEM (Science, Technology, Engineering and Mathematics). The article analyzes the aspects of the concept of STEM implementation in the educational sector of Ukraine. The analysis of scientific works on the development of STEM education allowed to establish the features of teaching physics, taking into account current trends in education. The components of STEM teaching of physics include means of blended learning in combination with cloud-based technologies. This concept is especially relevant in the context of the COVID-19 pandemic. Seven models of blended learning, which are the most common in educational practice in Ukraine, are analyzed. The concepts of compositional combination of full-scale experiment with the use of digital laboratories, cloud services and BYOD (Bring Your Own Device) technologies as tools for the implementation of blended learning in the STEM system are outlined. Guided by the recommendations of the state program to improve the quality of natural and mathematical education, the emphasis is on the use of modern experimental tools and digital laboratories. The use of digital laboratories makes it possible to organize a physical experiment at a fundamentally new level. An example of a complex study of mechanics using a digital laboratory, cloud services and BYOD technology is given. The results of the pedagogical experiment convincingly prove that the technologies of blended learning with the use of cloud services and BYOD tools are a powerful tool in the work of teachers.

Keywords: STEM education, BYOD, blended learning, digital lab, physical experiment

1. Introduction

Ensuring the competitiveness of Ukraine as a European state is possible by combining the interaction of economy, education and science with the active introduction of innovations in all spheres of human activity. Today's requirements for the training of specialists capable of innovative activities update the quality of education, in particular natural-mathematical and technological components, encourage its modernization through the introduction of new educational technologies, including the introduction of STEM direction. This direction arose at the request of modern business, which requires professionals in new industries and involves a combination of natural sciences and mathematics and engineering [10, 11, 17]. The introduction of STEM in the education sector changes the economy, makes it competitive and innovative.

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The order of the Cabinet of Ministers of Ukraine of January 13, 2021 № 131-r provides for the implementation of a number of measures to implement the Concept for the development of natural and mathematical education (STEM education) until 2027, related to the formation and development of research and engineering skills, invention, entrepreneurship, early professional self-determination, popularization of scientific, technical and engineering professions [14].

Recently, the STEM education department of the Institute of education content modernization developed methodological recommendations for the development of STEM education in general secondary and out-of-school education institutions in the 2021/2022 academic year. Here, in particular, it is stated: "In the implementation of STEM training on the principle of integration, project activities are relevant. The implementation of STEM projects involves integrated research, creative activities of students aimed at mastering the methods of scientific knowledge and their practical implementation, in particular, in everyday activities, finding ways to solve problems, critical evaluation of the results and scientific worldview formation [6].

Some aspects of the introduction of STEM education were considered by National Academy of Engineering and National Research Council [13] (STEM integration as an important innovation of the modern educational paradigm), Lin, Wang and Wu [7] (design and implementation of interdisciplinary STEM instruction), Slipukhina et al. [19] (features of application of the multidisciplinary approach in STEM training, engineering methods in science education), Sharko [18] (methods of teaching natural sciences and mathematics in secondary and higher education institutions using STEM education technologies). Educational robotics and game-based learning were researched by Morze and Strutynska [12], Papadakis and Kalogiannakis [15], Tzagkaraki, Papadakis and Kalogiannakis [20].

Our analysis of scientific works on the development of STEM education allowed to establish the following features of teaching physics, taking into account current trends in education:

1. focus on personality-oriented learning and widespread introduction of integrated education using STEM technologies;
2. the ratio and combination of the humanities and natural sciences, which, accordingly, relates to the teaching of physics;
3. introduction of digital and cloud learning technologies raise physical education to a new higher level;
4. popularization of technology and engineering within STEM education;
5. taking into account the results of psychological and pedagogical research in the analysis of the content of the physical experiment in the context of the development of STEM education.

In the context of this, the method of teaching physics in terms of STEM training is focused on the current state of technology, taking into account the latest achievements of psychology and educational sciences. This helps to increase the activity of students in mastering new skills and knowledge, and the focus of the educational process on future professional activities. The components of STEM physics training include blended learning tools in combination with cloud-based technologies. This concept is especially relevant in the context of the COVID-19 pandemic [16]. The classification of STEM technologies for teaching physics is given in figure 1.

Blended learning is an educational concept in which a student acquires knowledge both independently online and in person with a teacher. This approach makes it possible to control

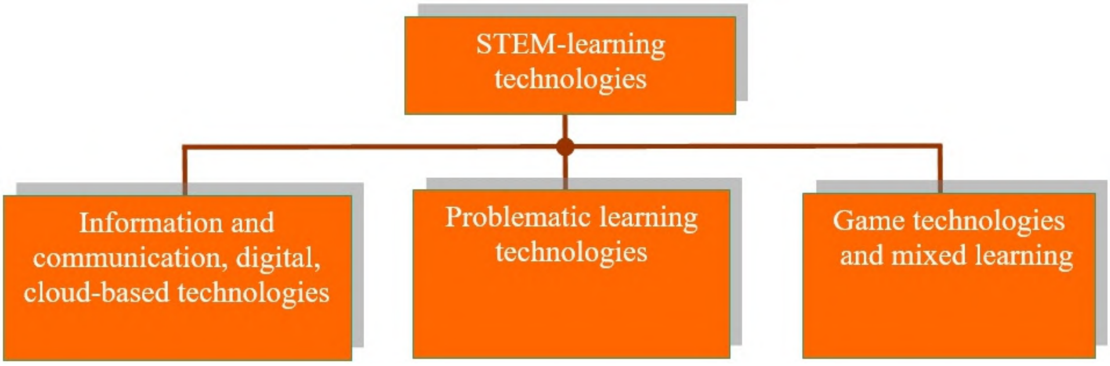

Figure 1: Classification of STEM technologies for teaching physics.

the time, place, pace and result of learning the material and allows you to combine traditional techniques and modern technologies [1]. Along with this, blended learning has a number of advantages:

- individualization of training;
- opportunity for self-development, independent learning;
- motivation for students, the emergence of a sense of success;
- effective use of study time;
- use of advanced diagnostic tools;
- formation of team work skills;
- establishing partnerships between teachers, students and parents;
- saving of material resources;
- raising the level of digital literacy;
- changing priorities for the use of Internet resources (focus on educational material, not on social networks and games).

These advantages of blended learning successfully implement the concept of the New Ukrainian School [21], consolidate the educational process, and thus provide quality formation of the main key competencies of the graduate of the educational institution, including:

- basic competencies in natural sciences and technologies;
- information and digital competence;
- ability to life long learning;
- mathematical competence;
- initiative and entrepreneurship;
- social and civic competence;
- environmental literacy and healthy living.

When organizing the educational activities for a group of students, the teacher must have different models of blended learning. There are different approaches to their classification. We propose to consider seven models that are most common in educational practice [2]: face-to-face driver model, rotation model, flex model, online lab model, self-blend model and flipped classroom model. In all cases, blended learning is characterized by three main components:

1) component of traditional direct personal interaction of participants in the educational process;
2) component of interactive interaction mediated by computer telecommunication technologies and electronic information and educational resources.
3) component of self-education.

In the process of teaching physics, the most optimal models are: the flipped classroom model and the model of reinforcement of traditional learning (face-to-face driver), because the rest of them are implemented mainly through distance learning, so their use in the learning process in physics is limited. For effective physics learning it is important to experiment, which can be implemented in the process of full-time training. Therefore, the problem of implementing the method of compositional combination of field experiment, cloud services and the use of BYOD technologies as a tool for the implementation of blended learning in the system of STEM education is relevant [3, 8]. Equally important is the development of methodological recommendations to ensure the education of scientific and applied (professional) direction.

The purpose of the article is to outline the concept of compositional combination of full-scale experiment with the use of digital laboratories, cloud services and BYOD technologies as tools for the implementation of blended learning in the system of STEM education.

2. The theoretical backgrounds

Implementing and using of blended education has advantages, which positively influence educational process effectiveness:

- scaling, allows you to significantly increase the audience of participants in the educational process through electronic (distance) learning using cloud technologies;
- speed, you can teach many people at the same time on the material that was developed for one participant;
- mobility, is provided with the opportunity to learn at any time, from anywhere.

The blended nature of learning involves a combination of different forms and systems of learning:

- classroom training in the presence of a teacher, which involves direct contact of students and teachers;
- interactive learning – online learning (e-learning), which is carried out using an instrumental environment (e-learning course, virtual classes and laboratories, conference calls, individual counseling via e-mail, discussion forums, chats, blogs);
- training with the support of various cloud-based tools and educational materials.

The information and technological system of blended learning provides users with e-learning materials, as well as the opportunity to ask questions and communicate with the teacher, to conduct independent testing. The use of cloud technologies opens wide opportunities for interactive blended learning. Having acquired theoretical knowledge, the basis and basis for the transition to intensive practical training is created, which can be carried out in person or remotely. In these two cases, logistics is important. Currently, modern tools and technologies are being actively introduced into all spheres of human life, which requires teachers to use devices and equipment in their work that promote the development of motivation to learn, which, in turn, will improve the cognitive activity of students.

The use of digital laboratories makes it possible to organize a physical experiment at a fundamentally new level, to move to the elements of scientific knowledge, from qualitative assessments of the studied phenomena to a systematic analysis of their quantitative characteristics [5, 9]. The use of digital laboratories in the educational experiment in physics helps to increase interest in the study of the subject and the formation of the experimental component of subject competence. The digital laboratory is a modern universal computerized system used for a wide range of research, demonstrations, laboratory work in physics, chemistry and biology. The use of digital laboratories allows you to get an idea of related educational areas:

- information technology;
- functions and graphs, mathematical processing of experimental data, statistics, approximate calculations;
- methods of conducting research, compiling reports, presentation of work performed.

Compared to traditional equipment, digital laboratories provide the ability to:

- reduce the time spent on the preparation and conduct of a frontal or demonstration experiment;
- increase the visibility of the experiment and visualization of its results, expand the list of experiments;
- process and analyze experimental data with great accuracy;
- perform measurements in the field;
- modernize the traditional experiment;
- create videos of demonstration experiments, which allows you to form your own bank of clarity;
- compare the data received in the course of carrying out experiments, and to carry out serious statistical processing of results;

However, there are also difficulties that may arise when working with a digital laboratory:

- inability to obtain appropriate graphical dependencies (due to the significant number of measurements per unit time), which sometimes distorts the content of the results;
- during the processing of graphs quite complex transformations are used, which are not always clear to students;
- there is a need for additional time to explain the material related to the use of digital laboratories.

3. Findings

The main *purpose* of the pedagogical experiment is to establish the degree of influence of the proposed method of using STEM equipment on the effectiveness of teaching physics, to increase interest in its study and acquisition of knowledge by students of general secondary education.

The organization of the pedagogical experiment was based on the *hypothesis* that the proposed method of forming students' experimental abilities based on the use of modern digital equipment will effectively influence the formation of experimental skills, activities, information concepts and increase interest and level of student achievement.

The content of the pedagogical experiment involved the solution of many problems, among them we consider important from the point of view of research:

1. Establishing and formulating problems and difficulties in forming students' experimental skills, finding ways to solve them, formulating a research hypothesis.
2. Analysis of the approaches to the organization and conduct of educational physical experiment described in the methodological literature, features of their use in the educational process.
3. Development of new means of forming students' experimental skills based on mobile and remote technologies and methods of their application in the educational process.
4. Development of instructional and methodical materials.
5. Verification of pedagogical efficiency of methodical approaches, receptions and ways of application of author's developments of formation of experimental skills and reliability of the accepted hypothesis of research.

At the stage of the observational experiment, the problems of using digital equipment (digital laboratories, gadgets, etc.) in the practice of teaching physics in general secondary education, as well as the availability of methodological developments (recommendations) for the use of such equipment were studied.

It is established that the programs for general secondary education institutions in Ukraine (basic, academic and profile levels) do not specify such use of funds, and textbooks for students contain laboratory work that is not based on the integrated use of digital systems and mobile technologies.

The observational experiment showed considerable interest of students and teachers in the use of STEM tools in the educational process in physics, in particular for the formation of experimental skills. The availability of appropriate equipment (tablets, smartphones, etc.) contributed to this increase in interest. At the same time, during the experiment it was found that more students than teachers are interested in independent experimental work, respectively 65% and 29% of respondents. It is established that the greatest interest for the student is such a form of classes as laboratory work using STEM tools. 75–80% of respondents in the profile classes expressed their opinion. Among them, about 50% of those who have difficulty processing research results, and only about 30% of those who use software to process data and build graphical dependencies.

In general, 60–85% of respondents (students and teachers) in each class said that it is important to conduct a full-scale experiment, and to carry out comprehensive processing of experimental results with modern digital tools to build graphical relationships between physical quantities.

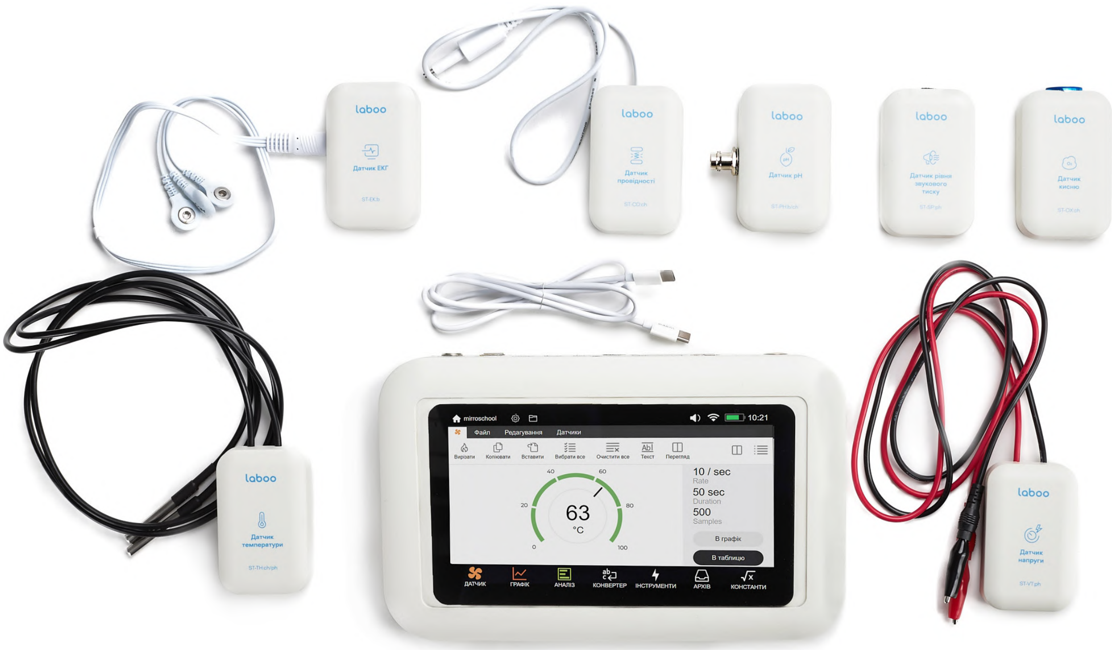

Figure 2: Digital measuring complex *Skoolto* (https://mirroschool.com/product/40338/).

Currently, a large number of different digital laboratories and measuring systems have been developed. Currently popular are: *Einstein* digital measuring system [4]; digital laboratories *LabDisc*, *Relab*; software and hardware complex *AFS* ("All For School"); digital laboratories of the German company *PHYWE*, specially designed for the school curriculum; *NOVA 5000* is a specialized portable computer from Fourier Systems, with a built-in data logger – a computer for the science room.

In the process of analyzing user feedback, we found that the issue of methods of using digital measuring systems in general secondary education and higher education institutions is not sufficiently developed. We propose to use a digital laboratory in combination with cloud services and BYOD technologies to implement blended learning. Consider the example of using the digital measuring system *Skoolto* (figure 2).

Unlike similar equipment, the proposed option has a number of advantages: much lower cost, convenient and clear interface in Ukrainian, a large number of necessary sensors, graphical visualization of data, definition of basic parameters, their storage, export to conventional formats (XLS, PDF). Another feature of the complex is the ability to connect to the network, which allows to download the results of the experiment.

Consider an example of a comprehensive implementation of the study "Movement of the body on an inclined plane". In the course of experiment performance researches of characteristics of movement of a body on an inclined plane (figure 3) on the basis of analyzes of the schedule of dependence of movement on time are carried out. The experiment is performed by the teacher in the lesson, or conducts a video broadcast using the Google Meet service.

The teacher performs the experiment several times, changing the angle of the plane. The

Figure 3: Experimental setup to study the characteristics of body motion on an inclined plane.

result of the experiment are graphs describing the movement of the cart on an inclined plane, which the teacher exports to a spreadsheet editor with the XLS extension for further analysis by students. Conclusions on the results of the work performed by students are announced in class, or sent for review using the Google Classroom service. To conduct the experiment at home, the teacher suggests using the mobile application Phyphox. Phyphox is a very convenient free application that allows you to perform measurements and research with all smartphone sensors (gyroscope, magnetometer, light sensor, barometer, accelerometer, etc.), record results, present them graphically, as well as store and disseminate experimental results (figure 4). It has the following features:

- the presence of all necessary sensors in one environment, it is not necessary to download a separate application for each sensor;
- the ability to export data in a MS Excel spreadsheet in XLS format;
- the ability to record the results and present them graphically;
- Phyphox can be controlled remotely from any device that is on the same network as the smartphone and has a modern web browser;
- The application allows you to create your own experiments using a visual experiment editor.

To perform the research, the teacher recommends previewing the video, which explains the sequence of actions, and make an experimental setup from the improvised materials that everyone has. An inclined plane can be any board resting on a stand (for example from books). Height can be measured with a ruler. To use a smartphone, it is necessary to place it in a cylinder (for example, an empty case of chips) and fix it with foam or paper (figure 5).

Students perform research based on the recommendations they see in the video and send a report on the work done: the results obtained in the form of graphs, a table with the obtained data, calculations, conclusions to the work.

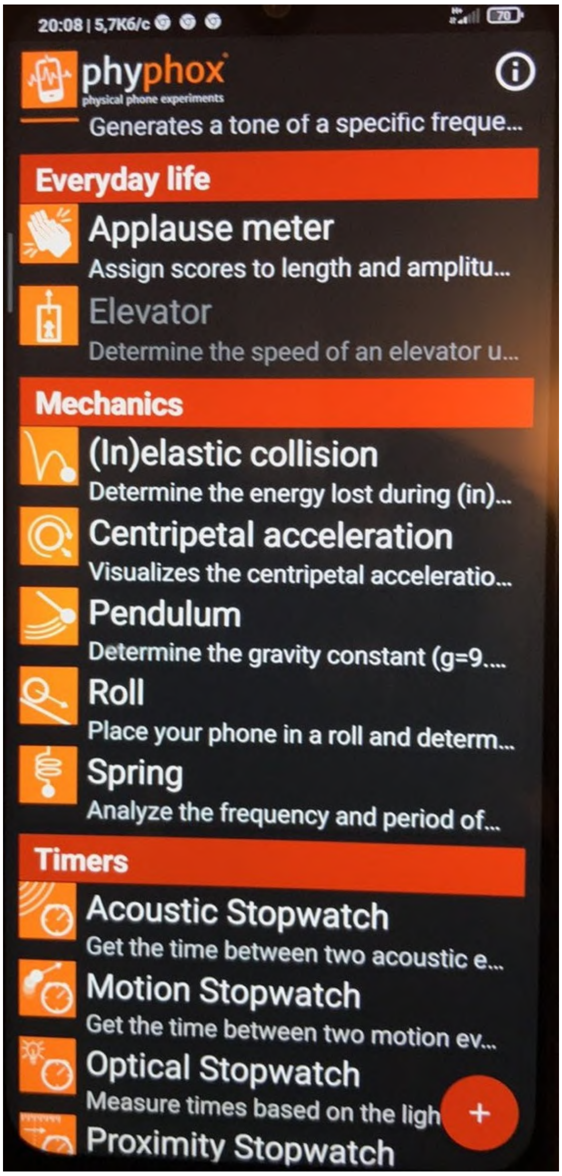

Figure 4: Phyphox at work.

Based on the use of the proposed tools in the educational process of the general secondary education institutions of Ukraine identified by us, a formative pedagogical experiment was conducted.

The purpose of the formative pedagogical experiment is to test the effectiveness of the method of using the digital laboratory, cloud services and BYOD tools. The method of forming students' experimental skills was tested and implemented. Among the research methods used: questionnaires of students, their testing, observation of the learning process, statistical data processing. At the final stage, the control of academic achievements of students of experimental

Figure 5: Smartphone mounted in a cylinder.

and control classes was carried out. According to the results of the pedagogical experiment, a significant change in the indicators of increasing interest, motivation, creativity in students to study physics (table 1). At the same time, the above-mentioned indicators for students in the control classes remained within the statistical error.

The results of the pedagogical experiment show that teaching students with the use of STEM technologies increases the level of skills to pose a problem, search for its solution, conduct experimental research, processing the results of the experiment, which generally provides the formation of meta-subject experimental skills.

Table 1
The results of the formation of experimental skills of students of the experimental group.

Index	Indicators	
	Before the experiment, %	After the experiment, %
Interest in studying physics	30	60
Motivation to perform experiments	35	65
Creativity	20	40
Methods of activity, reflection	30	65
Indicator of the formation of experimental skills	40	70

4. Conclusion

The use of blended learning in the educational process contributes to the intensification of the learning process, providing constant access to educational resources at any time and in any place. The concept is a powerful tool for forming a person of the information society, capable for self-improvement throughout life. Our pedagogical experiment proved that blended learning technologies using cloud services and BYOD tools provide the teacher with powerful tools to achieve this goal. Developed and adapted methodological and technical tools for remote support of educational physical experiment meets the implementation of organizational and methodological requirements in the implementation of STEM education. The preparation of students according to our proposed method of using mobile tools during blended learning increases the level of skills to pose an experimental problem and look for ways to solve it, which ensures the formation of subject and digital competence of students.

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