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STEM EDUCATION IN PHYSICS: DEVELOPMENT OF A LABORATORY STAND FOCUSED ON THE IMPLEMENTATION OF MINI-PROJECTS

Abstract. Currently, new technologies are widely used in the context of the development of the information society, secondary and higher education. The use of digital tools, STEM resources, 3D modeling programs and 3D printing equipment, laboratory stands made with their own hands has been widely used in the educational process. All these conditions are aimed at preparing future specialists to meet the requirements of the XXI century. Physics as a fundamental science is one of the fundamental disciplines in the field of STEM. Therefore, the use of STEM elements in teaching physics has a huge impact on the development of the activities of future specialists in the engineering and technical field. Especially STEM products and laboratory stands, developed by students in conjunction with the teacher's guidance, increase the effectiveness of the educational process. This will make it possible to create creative products and thereby develop the scientific and technical industry of the country. The purpose of this study is to implement physics education in universities on the basis of interdisciplinary connections through mini-projects and the development of educational and research stands and to determine the features of their implementation in the educational process. The research used methods of systematic analysis of articles published in highly rated journals, 3D modeling and printing methods, as well as constructive research methods. In addition, qualitative research methods were used in the pedagogical process. The results of the study showed that the development of laboratory stands for the implementation of mini-projects, thereby developing the creativity of students, is of great importance. It became known that students are actively involved in engineering, are interested in this area and increase their knowledge level when performing mini-projects. The results of the study will allow new areas of research to appear in the future, improve the methodology of teaching physics at universities, combine knowledge with science and industry.

Keywords: STEM education, teaching physics, student, mini-project, laboratory stand, creativity.

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Физикадан STEM білім беру: мини жобаларды іске асыруға бағдарланған зертханалық стендін әзірлеу

Аңдатпа. Қазіргі таңда ақпараттық қоғамды, орта және жоғары білім беруді дамыту контексіне сәйкес жаңа технологиялар кеңінен қолданыла бастады. Білім беру үдерісіндегі цифрлық құралдардың, STEM білімге негізделген ресурстардың, 3D модельдеу бағдарламалары мен 3D басып шығару жабдықтарының, қолдан әзірленген зертханалық стендтердің қолданылуы кең өріс алды. Бұл жағдайлардың барлығы болашақ мамандардың XXI ғасырдағы талаптарды орындай алуына даярлауға бағытталған. Физика іргелі ғылым ретінде STEM саласының негізін құраушы пәндердің бірі болып табылады. Сондықтан да физиканы оқытуда STEM элементтерін қолдану болашақ мамандардың инженерлік-техникалық саладағы іс-әрекеттерін дамытуға зор ықпал жасайды. Әсіресе, білім алушылардың оқытушы басшылығымен бірге жасаған STEM өнімдері, зертханалық стендтері білім беру үдерісінің тиімділігін арттырады. Сонымен қатар, креативті өнімдерді жасауға және сол арқылы еліміздің ғылыми-техникалық саласын дамытуға жол ашады. Бұл зерттеудің мақсаты – жоғары оқу орындарында физиканы пәнаралық байланыс негізінде оқытуды мини жобалар арқылы іске асыру және оқу-зерттеу стендтерін әзірлеп, оларды оқу үдерісіне ендірудің ерекшеліктерін айқындау болып табылады. Зерттеу барысында жоғары рейтингті журналдарда жарияланған мақалаларға систематикалық талдау әдістері, 3D модельдеу және басып шығару әдісі, зерттеудегі конструктивтік әдісі қолданылды. Сонымен қатар, педагогикалық үдерістегі зерттеудің сапалық әдістері пайдаланылды. Зерттеу нәтижелері көрсеткендей, мини жобаларды орындауға, сол арқылы білім алушылардың креативтілігін дамытуға зертханалық стендтерді әзірлеудің маңызы зор екендігі байқалды. Білім алушылар инженерлік іс-әрекетке белсенді қатысатындығы, олардың бұл салаға қызығатындығы және мини жобаларды орындауда білім деңгейлерінің артатындығы белгілі болды. Зерттеу нәтижелері болашақта жаңа зерттеу салаларының пайда болуына, жоғары оқу орындарында физиканы оқытудың әдістемесін жетілдіруге, білімді ғылыммен және өнеркәсіппен ұштастыруға мүмкіндік береді.

Кілт сөздер: STEM білім, физиканы оқыту, білім алушы, мини-жоба, зертханалық стенд, креативтілік.

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STEM образование по физике: разработка лабораторного стенда, ориентированного на реализацию мини-проектов

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Аннотация. В настоящее время в соответствии с контекстом развития информационного общества, среднего и высшего образования широко применяются новые технологии. Широкое распространение получило использование в образовательном процессе цифровых инструментов, STEM-ресурсов, программ 3D-моделирования и оборудования для 3D-печати, лабораторных стендов, изготовленных своими руками. Все эти условия направлены на подготовку будущих специалистов к выполнению требований XXI века. Физика как фундаментальная наука является одной из основополагающих дисциплин в области STEM. Поэтому применение элементов STEM в обучении физике оказывает огромное влияние на развитие деятельности будущих специалистов в инженерно-технической сфере. Особенно STEM-продукты, лабораторные стенды, разработанные обучающимися совместно с руководством преподавателя, повышают эффективность образовательного процесса. Это позволит создавать креативные продукты и тем самым развивать научно-техническую отрасль страны. Целью данного исследования является реализация обучения физике в вузах на основе межпредметных связей через мини-проекты и разработка учебно-исследовательских стендов и определение особенностей их внедрения в учебный процесс. В ходе исследования использовались методы систематического анализа статей, опубликованных в высокорейтинговых журналах, методы 3D-моделирования и печати, а также конструктивные методы исследования. Кроме того, использованы качественные методы исследования в педагогическом процессе. Результаты исследования показали, что разработка лабораторных стендов имеет большое значение для выполнения мини-проектов, развивающих креативность обучающихся. Стало известно, что обучающиеся активно участвуют в инженерной деятельности, интересуются этой областью и повышают уровень знаний при выполнении мини-проектов. Результаты исследования позволят в будущем появиться новым областям исследований, усовершенствовать методику преподавания физики в вузах, совместить знания с наукой и промышленностью.

Ключевые слова: STEM образование, преподавание физики, обучающийся, мини-проект, лабораторный стенд, креативность.

Introduction

In modern education, it is important to take into account the requirements of employers. Therefore, in the process of higher and secondary education, both in developed countries and outside the city, attention is paid to the creative, productive activities of students. The competency approach to higher education programs aims to prepare students for public and government needs. Especially in recent years, research on Advanced Technologies has increased to improve education in engineering and technical fields. Obviously, the development of Science and technology contributes to the development of the country's economy. Physics as a discipline makes a great contribution to this area [1].

As evidenced by the increased attention of the state order to the technical industries in the country, the number of annual grants. And this is the lack of grants, the lack of interest of school graduates in this area, and the low quality of Education cause concern for the future. The integration of STEM education plays an important role in eliminating such shortcomings.

The results of students ' training in the framework of physical disciplines are reflected in the assimilation of specific elements of their socio-economic experience. The results of training are a mirror of applied orientation in physics both within the framework of education and in real life situations. The results of modern education are measured by the development of students ' scientific worldview in the field of physics. The implementation of this need poses a great task for methodologists and teachers in physics. Therefore, higher education institutions, as research

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organizations, need to use methods and technologies that allow solving urgent problems of modern education and develop them further [2].

In order to improve learning outcomes in physics education, several works on the use of digital technologies, Stem products, and mini-projects can be cited [3]. For example, G. Tuyizere & L. Yadav [4] in their research proves the effectiveness of integrating interactive computer modeling into teaching physics and studying patterns. N. Nazifah & A. Asrizal [5] emphasizes the need to develop special educational materials for the effective implementation of interdisciplinary connections of STEM technologies in physics teaching. In addition, they believe that the use of a STEM product in teaching physics will have a huge impact on the development of 21st century skills among students.

Scientists of the Republic of Kazakhstan A. Iskakova & A. Kairbayeva [6] in her scientific article, demonstrated that using the Electronics Workbench computer program to teach physics based on projects forms students' skills necessary in teamwork, design and research.

The above-mentioned works formed the basis of our research work and allowed us to identify the following scientific problems:

- What are the possibilities of implementing mini-projects in teaching physics?
- How do we develop STEM products and relate them to educational and laboratory work?
- How do we implement the development of laboratory stands in physics?
- How we evaluate the learning outcomes of STEM education, etc.

Determining the solution to these above-mentioned problems is the main idea of our study. To do this, we will reveal the meaning of the main key words on the research topic and explain them based on the scientific works of Turkish and Kazakh scientists.

K. Sungur Gül & A. Saylan Kirmizigül conducted research in the field of organizing experiments using the Algodoo program for future science teachers and determining its impact on the level of education of science teachers, saying that STEM is an effective technology for teaching physics [7]. G. Kazbekova, Zh. Ismagulova note in their works that the versatility and complexity of STEM learning can be simplified by developing various programs. In addition, scientists outlined the main approaches to the development of these programs [8].

Analyzing the data presented in the scientific and methodological literature, we gave an idea of the concept of a mini-project - a means of implementing the student's research and creative activities through small groups designed to solve one small problem in the field of physics. These definitions allowed us, by conducting a survey of physics students, to identify selected physics topics, develop laboratory stands on these topics and evaluate its effectiveness in the implementation of mini-projects.

Research methods and materials

We conducted a two-stage analysis of articles from top journals on theoretical research methods. At the first stage, we collected works published over the past 5 years on the keywords “STEM education”, “Physics projects”, “STEM projects”, “Teaching Physics”, “STEM in Physics”. After reading the list of identified articles, we selected articles close to our topic. In the second stage, we filtered the articles by associating keywords with the headings of articles written in Excel. We conducted a systematic analysis of the remaining articles and compared the research results of the Republic of Turkey and Kazakhstan in this area.

In accordance with the objectives of the research topic, IT education and robotics, digital training resources and programs, 3D-based computer programs were analyzed and the necessary ones were selected to improve the material and technical base necessary for mini-projects. In order to determine in which subjects the implementation of mini-projects is carried out, an analysis of educational programs was carried out and an interview was conducted with students. In general, more than 200 students from Khoja Akhmet Yassawi International Kazakh-Turkish University and

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Sakarya University took part in the interview. The interview was conducted on 5 main questions. During the interview, analytical work was carried out with students, and a clear answer was achieved by asking additional questions. The content of these questions is as follows:

- In what field of physics are you interested in participating in research activities?
- What current and selected physics topics do you know today?
- What subjects are you interested in in the field of physics and what mini-projects do you want to implement in teaching?
- How do you understand the content of STEM education and in which physics disciplines do you want to use it?
- What fields do you associate STEM with as the science of the future?

The interviews were conducted outside of class in each group and at 50-minute intervals in each group. According to the answers of the students, the keywords were written by experts. At the end, the results were analyzed and recommendations were developed.

A survey of the content of the discipline "alternative energy sources" in the physics educational program was conducted on the basis of STEM and 3D modeling technology to identify opportunities for improving the practice of using mini-projects. In this discipline, 210 students of the educational program "6B05348-physics", "6B01510-physics" of the Department of physics of the Khoja Akhmet Yassawi International Kazakh-Turkish University took part in the survey. The survey questions are presented in Table 1.

Table 1 – The content of the survey questions (for EP «6B05348-physics», «6B01510-physics»)

s/n	List of survey questions	Rating			
1	To what extent has the lab work done with STEM and 3D modeling expanded your understanding of physical phenomena?	1	2	3	4
2	How interesting was it to participate in the development of the laboratory stand and perform mini-projects through it?	1	2	3	4
3	To what extent did STEM and 3D modeling increase your interest in performing physical experimental work?	1	2	3	4
4	Do you consider it necessary that the use of mini projects be interactive in nature?	1	2	3	4
5	Do you think STEM technology will be useful to deepen your understanding of physical phenomena and laws in the discipline of alternative energy sources?	1	2	3	4
6	Do you want to use large-scale projects on alternative energy sources?	1	2	3	4
7	Do you want to master the development of laboratory stands, 3D modeling and printing of products yourself?	1	2	3	4
8	To what extent do you think STEM education contributes to the economic development of the country, the development of Science and technology in the country?	1	2	3	4

Students answered questions on a scale from 1 to 4:

1 – «not at all»;
2 – «at some point»;
3 – «at a good level»;
4 – «very high».

Having made conclusions on the research methods, based on the research methods used by us, the results were analyzed and final works were made. All answers of the study participants are checked on questionnaire sheets and processed using mathematical statistics.

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Results and discussion

Analysis of the results of the interview-the study of what subjects to implement and how to evaluate the development of laboratory stands in Physics in increasing the level of motivation of students at the Department of physics gave the following indicators:

- 55% of students showed a positive attitude to the development of laboratory stands for alternative energy sources, the implementation of mini-projects in this area as the best chapters of physics;
- As for the interest in the STEM field in teaching physics, about 70% of students believe that research activities are necessary in the profession of the future and associate the STEM field with alternative energy sources as the science of the future;
- Although most students show little knowledge of the characteristics of STEM education and mini-projects, it is important to improve their knowledge in this field, develop positive motivation to study physics, and also associate skills that will be useful in everyday life with relevant areas of physics.

In the study of the solar cell system, an analysis of technologies focused on research and its effective implementation was carried out. Using the latest capabilities of digital technologies, a method of modeling a solar cell system was used. This allows students to form primary research knowledge. The Matlab program was used to create models of photovoltaic systems of different Watt sizes. Further, in order to assemble a photovoltaic system and study the physical laws and mathematical equations in it, the authors' own laboratory stands were used. A list of research projects that can be performed at the stands has been developed. On them, students were offered group projects in the direction of physics.

Within the framework of the disciplines "alternative energy sources", "solar radiation and its secondary directions", "selected chapters of solar energy", STEM projects were implemented. A group STEM project was developed on the topic «efficient use of solar energy in agriculture», in which students showed indicators of the development of research activities within the framework of this project.

The results of the analysis of the scientific literature confirm that the field of physics is distinguished by the fact that more research work is carried out than other sciences. In the course of studying physics, students conduct many experiments, acquire theoretical knowledge in accordance with this experience, and further develop research in search of something new. This circumstance allows you to achieve the latest results in science, directs you to make discoveries [9].

In our research, we mean the research activities of future physics specialists, future physics teachers – "alternative energy sources", "sunlight and its secondary directions", "selected chapters of solar energy" which are distinguished by constant motivation in the implementation of mini-projects. And now let us give an example of the use of STEM projects in the above disciplines and thus the implementation of scientific research, taking into account that each of the views of steam reflects a field based on one or more disciplines.

According to the main idea of this study, the stage of effective implementation is presented in Figure 1 below.

According to the 1st Stage, students study the basic photoelectric characteristics of the solar element, physical phenomena and laws on which the principle of operation of solar cells is based. In addition, he will get acquainted with the methodology for assembling p-n transitions from reusable solid-state diffusion sources [10], the vacuum-thermal methodology for creating current-receiving contacts and glow plugs, scientific papers related to photovoltaic batteries developed by a new method based on crystalline silicon.

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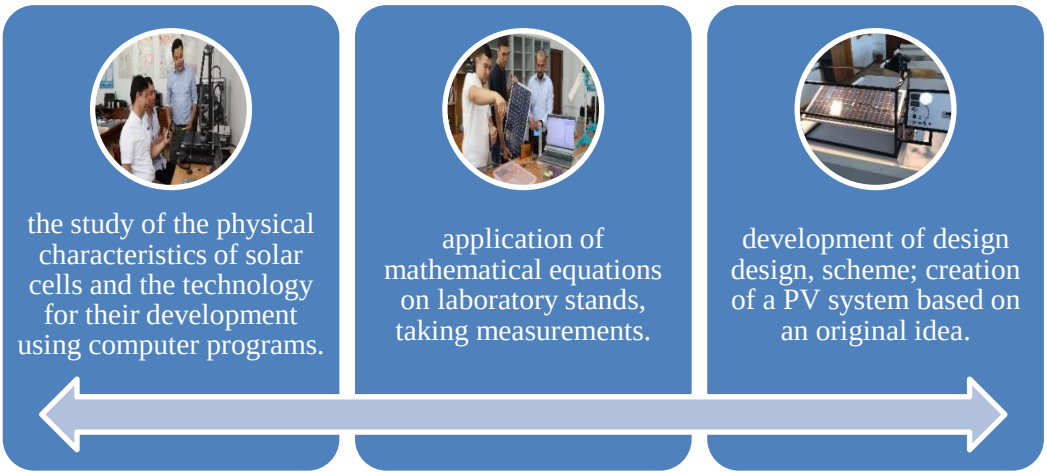

Figure 1 – Stage of effective implementation of the STEM project based on alternative energy sources

Students study the requirements for the source material and technological equipment for the production of solar cells (SC) used on earth, analyzing the modern technology for the production of Silicon SC, methods for reducing optical defects in the technology for the production of Silicon SC, modern technology for the production of silicon solar cells and photovoltaic plants, possible ways to obtain cheap solar cells.

Conducts mini-projects on the topics of “alternative energy sources”, “sunlight and its shielding directions”, “selected chapters of solar energy”, determining the efficiency of solar panels through solar research stands, direct conversion of solar energy into electricity, research of photovoltaic energy converter, operation of solar panels, the relationship of the angle of inclination of the solar panel to power, etc.

Let us give an example of the use of mini-projects in the educational process using a laboratory stand created by the author of the research group (figure 2).

Figure 2 – Research stand for the physical characteristics of the photovoltaic panel

Let’s dwell on one of the mini-projects performed with an author's stand, developed together with students.

Mini project theme: Determination of the Efficiency of the Solar Panel.

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The coefficient of efficiency - is one of the main characteristics that determine the efficiency of energy conversion. It is believed that the higher the efficiency of the device, the more energy efficient it is. The efficiency of a solar module depends on many factors (the structure and type of photocells, the angle of location of the panels depends on the direction of incidence of light, weather, operating temperature, etc.). In this paper, we will determine the efficiency of Monocrystalline panels.

In solar power, the efficiency of a solar module is considered as the ratio of the power of the P_{max} solar radiation falling on its surface at the standard solar radiation density 1 $\mathrm{kWt/m^2}$ of the electricity generated during the operation of the P_i photovoltaic converter.

$$\eta = P_{i'}/P_{max} \quad (1)$$

In addition, students are given the task of filling out the table below by working with a laboratory Stand (Table 2).

Table 2 – Determination of the efficiency of a monocrystalline solar panel

Point	Angle of inclination	Distance to the light source, m	Lighting intensity	Panel surface temperature, °C	Voltage, V	Current, A	COE, η, %
1	**90°**	$\mathbf{L_{max}}$ =	$\mathbf{I_1}$ =	$\mathbf{T_1}$ =	$\mathbf{U_1}$=	$\mathbf{I_1}$=	
2					$\mathbf{U_2}$=	$\mathbf{I_2}$=	

Undoubtedly, the development of a research tool in the verification of the laws of physics by the students themselves, thereby conducting research work and analyzing the results obtained, will increase their knowledge. Students have the opportunity to model the desired product using 3D printing and use it in the implementation of mini-projects. Complete safety and autonomy for the environment - the main criteria that prompted the design of a stationary FEF with a power of 140W for the operation of consumer household equipment (televisions, computers, etc.) and lighting of buildings are a photovoltaic installation, consisting of a photovoltaic battery with an area (glass size) of 1300x830x0.2mm3. Further, students carry out the final work of the work with mathematical calculations.

Figure 3 – Implementation of independent mini-projects by students

The results of the survey conducted on the discipline «alternative energy sources» in order to determine the importance of 3D models, STEM models, mini-projects in the interpretation of physical phenomena and patterns are presented in Table 3 below.

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Table 3 – Survey results

s/n	List of survey questions	Average value	Standard deviation
1	To what extent has the lab work done with STEM and 3D modeling expanded your understanding of physical phenomena?	3,4	0,6
2	How interesting was it to participate in the development of the laboratory stand and perform mini-projects through it?	3,5	0,5
3	To what extent did STEM and 3D modeling increase your interest in performing physical experimental work?	3,8	0,2
4	Do you consider it necessary that the use of mini projects be interactive in nature?	4,0	0,0
5	Do you think STEM technology will be useful to deepen your understanding of physical phenomena and laws in the discipline of alternative energy sources?	4,0	0,0
6	Do you want to use large-scale projects on alternative energy sources?	3,7	0,3
7	Do you want to master the development of laboratory stands, 3D modeling and printing of products yourself?	3,2	0,8
8	To what extent do you think STEM education contributes to the economic development of the country, the development of Science and technology in the country?	3,2	0,8

The content of the survey was aimed at determining how much STEM education, laboratory stand, mini-projects expanded their physical knowledge from future physics teachers. According to question 1,75% of the survey respondents said that education had an effect on expanding their understanding of physical phenomena at a «very high» level, while the remaining 25% indicated that the student was at a "good level". 90% of the students surveyed said that STEM education, a laboratory stand, was interesting at a "very high" level, while only 10% of the students expressed interest "in some cases". STEM showed that the increased use of knowledge, laboratory stand, mini-projects, and self-mastery of printing physical phenomena with 3D modeling were considered necessary by 80% of students at a "very high" level (figure 4).

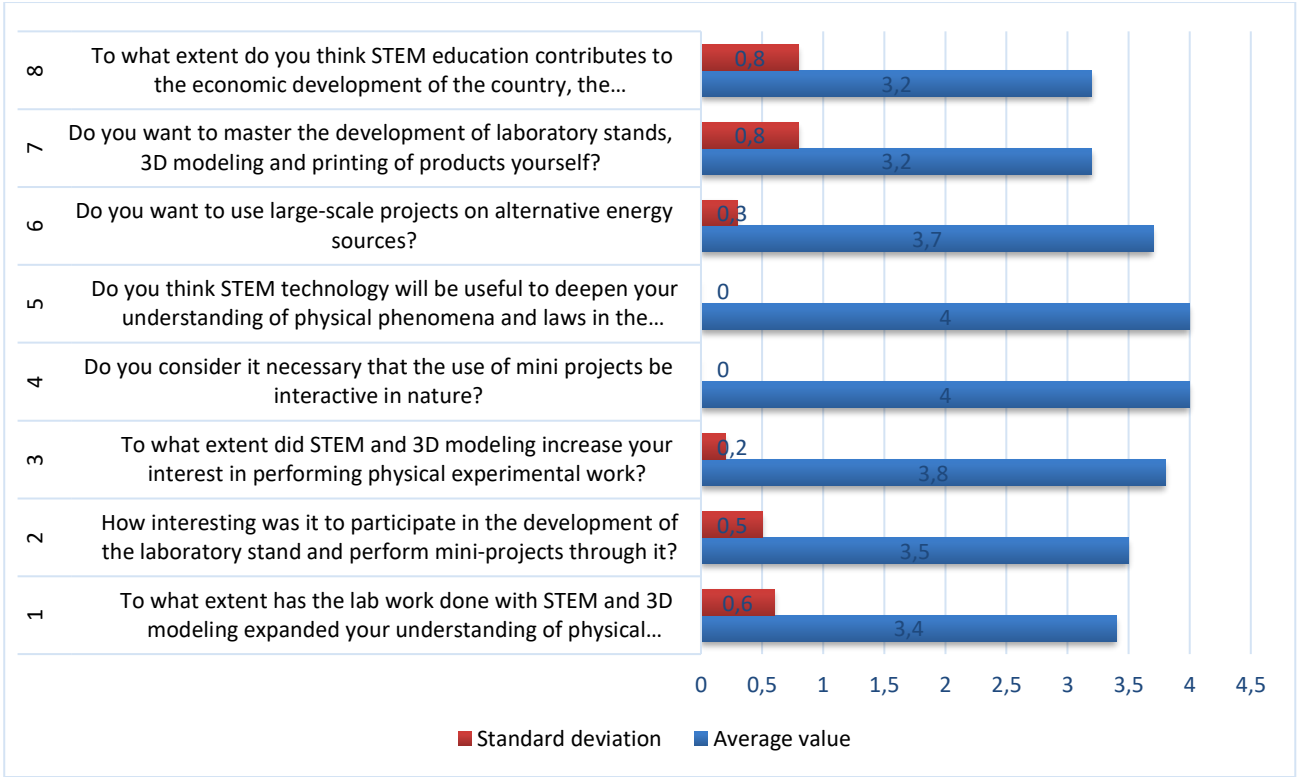

Figure 4 – Monitoring the effectiveness of the proposed methodology

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The results of the study show that the STEM project method can be used in the study of Fundamental Sciences of physics to develop scientific literacy of students. The results showed that most students were able to see the relevance of scientific knowledge to explain the phenomena that occur in the field of solar energy. Analysis of the aspect of scientific ideas in general means that the interest of students is growing, and they are capable of conducting simple scientific research.

The analysis of the results of the study revealed the knowledge and qualifications necessary for the development of students ' interest in physics and educational and research skills:

- ability to apply scientific research methods and make observations in natural phenomena, especially in the field of solar energy;
- planning and implementation of experiments in the implementation of mini-projects;
- processing of mathematical measurement results using tables and graphs, formulas;
- determine the dependence between physical quantities, interpret the results on the basis of STEM, draw conclusions;
- be able to understand the meaning of basic physical laws and apply them in engineering activities.

A comprehensive analysis, after quantitative and qualitative research methods, confirmed that the most effective technology for teaching the category of students of both countries mentioned above is STEM project technology.

Conclusion

In conclusion, based on the analysis of the existing system of training on the basis of STEM technology, 3D graphics, mini-project, laboratory stand, we showed the features of training students in the visualization of physical phenomena and patterns, in constructive actions. As can be seen from the analysis of the scientific literature in the course of the study, the results of the survey, the popularity of STEM technology, 3D graphics, mini-project, laboratory stand in the educational process is developing day by day. This area is increasingly focused around the world, especially in the training of future physics specialists at the university level. The effectiveness of the educational system, which uses STEM technology, 3D graphics, mini project, laboratory stands to help better understand physically complex phenomena and patterns, will be improved by the perception of theoretical and practical aspects of the subject under study by future physics teachers.

The results of the study show that the STEAM project method can be used in the study of Fundamental Sciences of physics to develop scientific literacy of students. The results showed that most students were able to see the relevance of scientific knowledge to explain the phenomena that occur in the field of solar energy. Analysis of the aspect of scientific ideas in general means that the interest of students is growing, and they are capable of conducting simple scientific research.

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