# Model of Professional Retraining of Teachers Based on the Development of STEM Competencies

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**Abstract.** The article describes a methodology for organizing lifelong learning, professional retraining of teachers in STEM field and their lifelong learning in Volodymyr Hnatiuk Ternopil National Pedagogical University (Ukraine). It analyzes foreign and domestic approaches and concepts for the implementation of STEM in educational institutions. A model of retraining teachers in the prospect of developing their STEM competencies and a model of STEM competencies were created. The developed model of STEM competencies for professional teacher training and lifelong learning includes four components (Problem solving, Working with people, Work with technology, Work with organizational system), which are divided into three domains of STEM competencies: Skills, Knowledge, Work activities. In order to implement and adapt the model of STEM competencies to the practice of the educational process, an experimental study was conducted. The article describes the content of the scientific research and the circle of respondents and analyzes the results of the research.

**Keywords:** model, professional retraining of teachers, lifelong learning, STEM competency, STEM learning, STEM competency research.

## 1 Introduction

The reorganization of the Ukrainian secondary school is a consolidated goal of Ukrainian society as a whole. The conceptual foundations for reforming secondary school determine the nine components of the "New Ukrainian School" [5], among which the new content, which is defined in the "Standard of general secondary education" [8] and focuses on the formation of key competencies for life, takes pride of place. These standards are based on the Recommendations of the European Parliament and of the Council of the European Union on Key Competences for Lifelong Learning [20].

Today, in Ukraine, the first steps are taken to introduce STEM learning, which will promote:

- modernization of the practical training of future teachers of natural and mathematical subjects and improvement of professional skills of teaching staff.
- lifelong learning, training and retraining of teachers of natural and mathematical subjects for ICT-supported STEM education and professional careers.
- refocusing from traditional subject learning to a competent approach.

STEM education is one of the most trending directions of the 21st century educational reform. The author [14] believes that any educational reform should take into account the readiness of teachers, especially in terms of their skills and competencies.

The authors [13] note the global need to improve education policy in the field of STEM. In the United States, during the last two decades, the educational reform of STEM has taken place. However, in practice, STEM teachers lack cohesive understanding of STEM education. The process of integrating science, technology, engineering, and mathematics into the authentic context is the basic concept of STEM education and requires a new generation of STEM experts. The researchers emphasize that the key to STEM teacher training lies in substantiating their conceptual understanding of the integrated STEM education system by teaching key educational theories, pedagogical approaches, and raising the level of STEM competencies.

Other authors [27; 17] believe that teachers are constantly faced with new learning strategies and methods needed to successfully implement STEM education. They encourage the development of STEM concepts that will help students understand how the four disciplines merge together to solve practical issues and real life problems [1].

The author [18] in her study emphasizes that STEM is a skill that contributes to a students’ crucial representation of how STEM ideas, standards and practices relate to everyday life experiences.

Vasquez, J., Sneider, C., Comer, M. [26] described four different approaches to STEM. The first approach is realized through a disciplinary form of integration, when the concepts and skills of STEM subjects are taught separately when studying each discipline. The second approach is realized through multidisciplinary integration, when the concepts and skills of STEM disciplines are taught separately. The third approach is realized through interdisciplinary co-ordination, where related ideas and positions are manifested in at least two elements of management in order to improve students' knowledge and their informative ability. Finally, the last approach is realized through transdisciplinary integration, where the knowledge and skills gained by means of at least two components of the interdisciplinary integration are related to real problems and projects.

Ejiwale J. [6] in his own study, identifies the barriers for STEM as an interdisciplinary study in K-12:

1. poor preparation and lack of qualified teachers;

2. lack of investment in PD teacher;
3. poor preparation and inspiration of students,
4. lack of communication with the individual
5. lack of support from the school system;
6. lack of STEM collaborative research;
7. poor preparation of the content;
8. poor delivery of content and evaluation methods;
9. bad terms and conditions;
10. lack of practical training of students.

Scientists [16] identified the critical components of STEM schools and received the theoretical basis of the eight main elements characterizing STEM higher education institutions: personalization of training; problem-based learning; strict training; school community and affiliation; external community; personnel funds; technology and life skills; career.

The STEM Connector's Innovation Task Force (SITF, USA) has developed new career paths in STEM-STEM 2.0. The work of [15] identified STEM competencies in the STEM 2.0 industry: professional skills 2.0, innovative, digital, and subject-specific (specific discipline) or so-called "solid" skills.

Problems of formation of STEM competencies in the synthetic learning environment are explored by Olga Pinchuk, Svitlana Lytvynova, Oleksandr Burov. The authors consider the main directions of development of such environments: 1) computer generation of virtual environments; 2) designing of remotely controlled robots; 3) improvement of the interface man-machine; study of the relevant aspects of human behavior [19].

By studying the conceptual apparatus of STEM education, authors [25] conclude that the simulation of the STEM-oriented learning environment is relevant. The methodological foundations of the organization of cloud-based learning environment for teaching mathematical disciplines and computer sciences have been developed by Mariya Shyshkina, Ulyana Kohut, Maya Popel. [23]. In the process of developing our model of professional training and retraining of teachers, we used the classification and system of ICT competencies by O.M. Spirin [24].

Jang, H. [12] explores the gap between education in science, technology, engineering and mathematics (STEM) and the necessary skills in the workplace in industry, academia, and government institutions. He assesses the impact of STEM concepts on curriculum modifications and the relevance of today's qualification frameworks used in education through a standardized working database that is operated and maintained by the US Department of Labor.

Therefore, the question arises about the professional training of teachers before the introduction of STEM into the learning process. As noted by [2; 4; 21; 22], teachers have repeatedly expressed the need to see examples from other teachers who implement integrated STEM lessons. Studying the best practices of STEM practice should be the basis for improving the skills of practicing teachers and their professional development. A number of modern studies [7; 9; 10; 11] has confirmed the effectiveness of this approach.

We can state that many scientific studies are devoted to the development of STEM education. In our research, we will focus on the professional retraining of teachers and the development of their STEM competencies.

Therefore, the purpose of the article is to create a model for professional retraining of teachers in order to develop their STEM competencies.

## 2 The Presentation of Main Results

Creation of a teacher training and retraining system based on the development of STEM competencies at the Volodymyr Hnatiuk Ternopil National Pedagogical University based on the Department of Computer Science and Teaching Techniques at the Faculty of Physics and Mathematics took place at the following stages: designing, constructive, analytical and corrective.

The designing stage involved strategic, conceptual and functional analysis. Strategic analysis considered the definition of general objectives for professional retraining of teachers based on the development of their STEM competencies and the construction of a model of STEM competencies. At the level of conceptual analysis, the structural components of lifelong learning, professional training and retraining of teachers in the field of STEM were developed and the theoretical foundations of STEM disciplines were determined. Functional analysis enabled to determine the content of STEM-oriented tasks and to identify practical projects.

The constructive stage involved the development of a model for lifelong learning, professional training and retraining of teachers based on the development of STEM competencies (Fig.1).

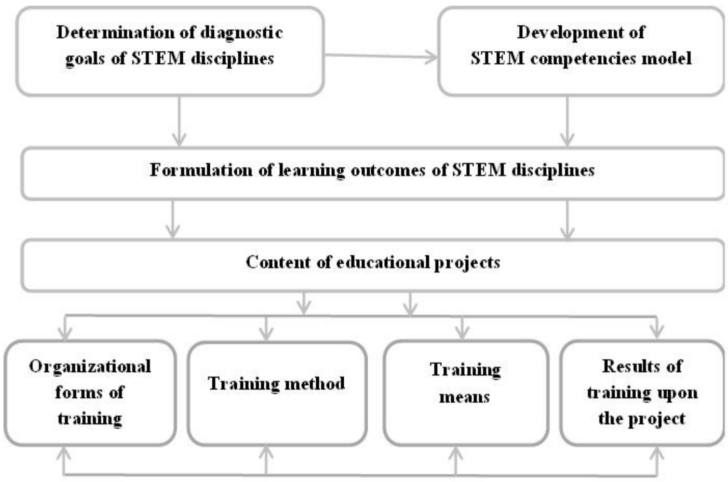


**Fig. 1.** A model for lifelong learning, professional training and retraining of teachers based on the development of STEM competencies

STEM competency is considered as a dynamic system of knowledge and skills, modes of thought, values and personal qualities that determine the ability to innovative activities: readiness for solving complex problems, critical thinking, creativity, organizational ability, cognitive flexibility, teamwork, emotional intelligence, assessment and decision-making, ability to interact effectively and negotiate.

The basic components of STEM competencies marked by many scientists [12; 23; 3] are:

- the ability to define a problem;
- the ability to formulate a research task and identify ways to solve it;
- the ability to apply knowledge in different situations, to understand the possibility of other points of view in solving problems;
- the ability to solve the problem unconventionally;
- the ability to apply higher order thinking skills.

The model of lifelong learning, professional training and retraining of teachers in terms of the development of STEM competencies at the university is based on the elaboration of educational disciplines and individual didactic elements on a multidisciplinary basis (integrated training according to certain topics, not individual disciplines) and project training.

The proposed model involves a combination of formal (learning sessions with STEM elements provided by the curriculum), non-formal (events taking place at STEM-center of Volodymyr Hnatiuk Ternopil National Pedagogical University) and informal education (self-education, scientific contacts regarding STEM education).

The formal component is implemented at three levels: (Table 1)

**Table 1.** Levels of life-long learning model

| Level | Participants | STEM elements |
|---|---|---|
| First | Bachelors | – To distinguish the notions of STEM education, STEM literacy, scientific literacy, STEM specialty, innovation, start-up, STEM project and to use them to search for information materials, for project development, STEM startup planning;<br>– To develop information materials on STEM projects that are implemented in the world or country and are suitable for adaptation in their community;<br>– To search for ICT tools for STEM education support that are related with their professional orientation |
| Second | Graduates | – To use ICT tools to support cross-disciplinary research and STEM training: virtual labs, virtual worlds, simulators, emulators;<br>– To apply innovative means to support research: robotics, research tools, 3D modeling and printing, |

| | | |
|---|---|---|
| | | programming of complex biological and ecosystems, social behavior, etc.;<br>– To develop guidelines for the use of ICT for STEM education |
| Third | Teachers (re-training and life-long learning) | – To search for ICT tools for STEM education support that are related with their professional orientation<br>– To develop guidelines for the use of ICT for STEM education<br>– To apply innovative means to support research<br>– To evaluate and predict the needs of the community that can be realized by means of STEM;<br>– To develop inter-subject projects in the field of STEM-education;<br>– To teach using case study technology and project method in STEM education |

The non-formal component is implemented in the form of mixed learning based on the STEM-center, created at the Department of Computer Science of the Volodymyr Hnatiuk National Pedagogical University in 2015. The Center's work is aimed at organizing lifelong learning, professional training and retraining of STEM teachers, research and project training in order to gather innovative teaching methods and increase the interest of teachers and students in the STEM sciences, and the creation of a practice base for the implementation of STEM education. The successful development of STEM education at the STEM Center is exercised through resource mobilization and collaboration between school teams and external participants such as higher education institutions, academic institutions, research laboratories, science museums, natural history centers, enterprises, public and other organizations during the learning and teaching process. The teachers of the Department of Computer Science place special emphasis on the cooperation of specialists of different fields in the development of a special learning environment using ICT.

STEM-center holds various events of interest for the development of STEM competencies:

- Days of science both at the university and in other educational institutions;
- scientific picnics;
- university Olympiads in programming and IT, code hours;
- Competitions, master classes, trainings, winter and summer STEM schools with gifted students;
- STEM-festival;
- Trainings for the improvement of skills and professional retraining of teachers of the city and region in the field of STEM education [3].

Informal component of STEM training at the University is provided by the independent work of students and teachers, by processing of modern scientific sources, communication with STEM specialists during round tables, seminars, conferences, discussion panels, webinars, and distance learning on various e-platforms.

In addition, the model of lifelong learning, professional training and retraining of teachers based on the development of STEM competency as an activity uses not only the context of learning, but also the social aspect of learning. In this case, learning takes place in the community of practitioners, and this helps the teacher to move from the initial understanding of STEM knowledge, skills and practice to achieving mastership.

To test the effectiveness of the model lifelong learning, professional training and retraining of teachers through the development of STEM competencies, we conducted a pilot study (analytical-adjustment stage). Thirty-two practicing teachers were the participants of the experiment. Eight groups were formed. Groups were formed on the mixed principle, each of them included a teacher of mathematics, physics, computer science, biology or chemistry.

The author's model of STEM competencies is based on the H. Jang model. It contains 37 criteria, which are grouped into three domains: Skills, Knowledge, Work activities. The selection of criteria is resulting from our experience in practical implementation of STEM projects in schools and universities.

At the first (qualifying) stage, we suggested that teachers evaluate their level of development of STEM competencies. The evaluation was carried out in a 5-point Likert-like scale based on the criteria proposed by H. Jang [12]. Among the significant number of criteria, we selected 37 major criteria, which were distributed into three domains of STEM competencies: Skills, Knowledge, Work activities. Each domain combined the criteria into the following groups (Table 2):

- problem solving (PS);
- working with people (WP);
- work with technology (WT);
- work with organizational system (WoS).

**Table 2.** Author's model of STEM competencies

| Domain | Problem Solving | Working with People | Work with Technology | Work with Organizational System |
|---|---|---|---|---|
| Skills | Critical thinking<br>Complex problem solving<br>Creative thinking | Communication skills<br>Ability to work in team<br>Social intelligence<br>Emotional intelligence | Installation of equipment<br>Programming<br>(Network & System Administration) | Systems analysis<br>Systems Evaluation<br>Decision making |
| Knowledge | Math<br>Computer Science<br>Native and | Knowledge of regularities, principles and methods of teaching | Computer Science<br>Basics of microelectronics | Knowledge of management principles |

| | | | | |
|---|---|---|---|---|
| | foreign languages | Assessment of learning outcomes<br>Get feedback<br>Knowledge of leadership technologies<br>Knowledge of teamwork techniques | | |
| Work Activities | Information analysis<br>Evaluation of information<br>Search for solutions<br>Verification and experimental confirmation | Command formation<br>Conflict Management<br>Coaching and development of others<br>Networking | Interaction with computers<br>Data processing<br>Перевірка обладнання, конструкцій або матеріалу<br>Checking equipment, structures or material | Development of goals and strategies<br>Monitor processes, materials, or surroundings<br>Work with resources |
| STEM Competencies | Skills of problem solving | Communication skills | Technological and engineering skills | System skills, resource management skills |

The average value of each group of criteria was calculated for each respondent based on the points by respondent (Table 3).

**Table 3.** Mean values of groups of criteria

| Groups<br>Responders | Points by respondent | | | |
|---|---|---|---|---|
| | PS | WP | WT | WOS |
| 1 | 0,55 | 0,39 | 0,47 | 0,34 |
| 2 | 0,45 | 0,43 | 0,53 | 0,53 |
| … | | | | |
| 32 | 0,58 | 0,68 | 0,66 | 0,53 |

We considered the mean value obtained by the respondent when self-assessing all 37 questions as a latent indicator of the level of development of STEM competencies. The normalized index In was found from the ratio:

$$I_n = \frac{s_i - N}{s_{max} - N} \quad (1)$$

where si is a total points by respondent i, smax is a maximum points available, N is a number of questions.

The normalized index was calculated based on the total respondent's points during self-assessing all 37 questions.

The mean values of normalized indexes obtained on the first stage are given in Table 4.

**Table 4.** Normalized Indexes of Criteria Groups (Qualifying Stage)

| | PS | WP | WT | WOS |
|---|---|---|---|---|
| Normalized index | 0,47 | 0,49 | 0,49 | 0,53 |

We evaluated the latent indicator of development of STEM-competencies according to the scale

- 0 – 0.25 – critical
- 0.25 – 0.5 – low
- 0.5 – 0.75 – sufficient
- 0.75 – 1.0 – high

According to the results of self-assessment of teachers on the first stage of the study, we can affirm the low level of their STEM competencies. To determine the statistical method of processing the results of the study, we checked the normality of the distribution of each of the samples (data from Table 3). The results of the statistical study of normality by the One-Sample Kolmogorov-Smirnov Test are presented in Table 5.

**Table 5.** Checking the results for the normality of each of the samples (qualifying stage)

| | | **PS** | **WP** | **WT** | **WOS** |
|---|---|---|---|---|---|
| Normal Parameters | Mean | 2,8791 | 2,9713 | 3,0191 | 3,0806 |
| | Std. Deviation | 0,31038 | 0,35051 | 0,34940 | 0,32123 |
| Most Extreme Differences | Absolute | 0,102 | 0,135 | 0,115 | 0,092 |
| | Positive | 0,092 | 0,135 | 0,115 | 0,054 |
| | Negative | -0,102 | -0,086 | -0,089 | -0,092 |
| Test Statistic | | 0,102 | 0,135 | 0,115 | 0,092 |
| Asymp. Sig. (2-tailed) | | 0,200 | 0,144 | 0,200 | 0,200 |

The graphical representation of the distribution is shown in Fig. 2.

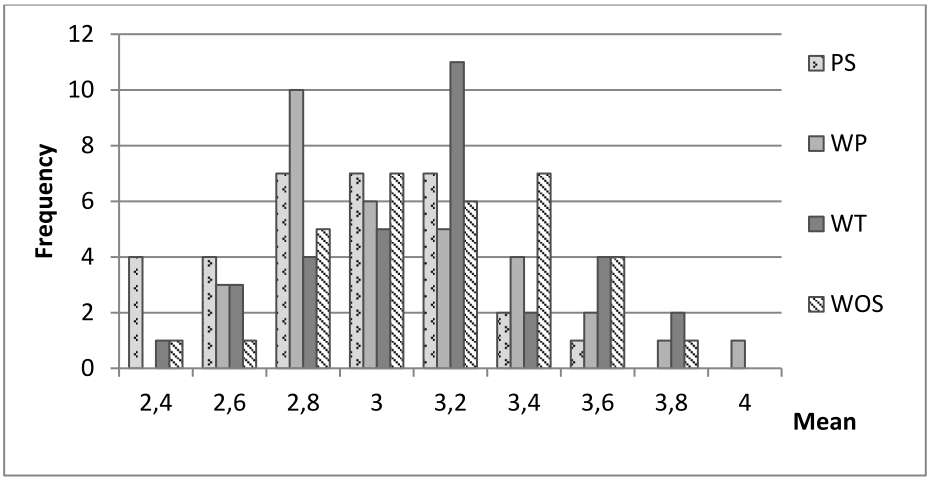


**Fig. 2.** Distribution of respondents by the mean value of groups of criteria (qualifying stage)

Based on the table data and the graphical representation of the distribution, we can assert the normal distribution of the samples.

At the second (exploratory) stage of the study, we developed the STEM competencies of teachers based on our model of lifelong learning, professional teacher training and retraining, and lifelong learning based on the development of STEM competencies.

It involved training of the established experimental groups of practicing teachers at the STEM Center and grounding of robotics, the Internet of Things, 3D technologies (computer 3D modeling and 3D printing systems), and their involvement in the execution of three STEM project tasks.

At the third (forming) stage, we again asked teachers to evaluate their own components of STEM competencies. The distribution of the samples at this stage also appeared to be normal (Table 6, Figure 3).

**Table 6.** Checking the results for the normality of each sample (forming stage)

| | | PS | WP | WT | WOS |
|---|---|---|---|---|---|
| Normal Parameters | Mean | 4,0213 | 3,9391 | 4,0162 | 3,9531 |
| | Std. Deviation | 0,26563 | 0,31254 | 0,40712 | 0,37995 |
| Most Extreme Differences | Absolute | 0,131 | 0,119 | 0,141 | 0,080 |
| | Positive | 0,131 | 0,119 | 0,077 | 0,071 |
| | Negative | -0,087 | -0,111 | -0,141 | -0,080 |
| Test Statistic | | 0,131 | 0,119 | 0,141 | 0,080 |
| Asymp. Sig. (2-tailed) | | 0,175c | 0,200 | 0,106 | 0,200 |

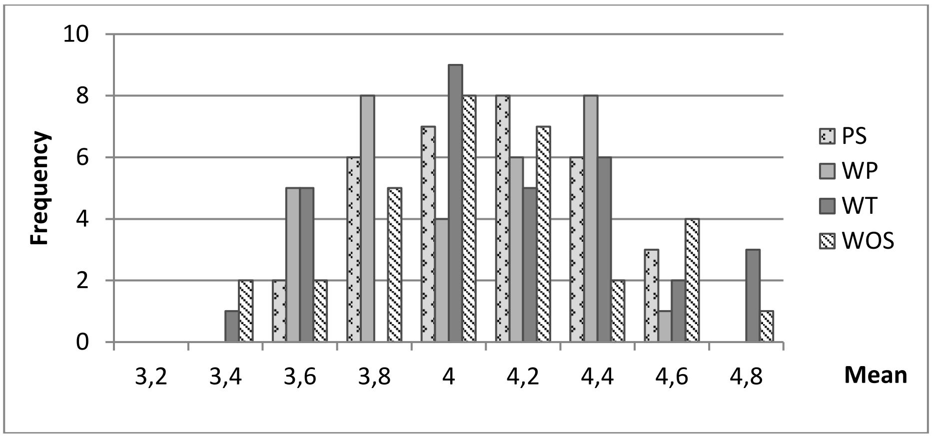


**Fig. 3.** Distribution of respondents by the mean value of groups of criteria (forming stage)

The results of calculations of average values of normalized indexes are given in Table 7:

**Table 7.** Normalized indexes of criteria groups (forming stage)

| | PS | WP | WT | WOS |
|---|---|---|---|---|
| Normalized index | 0,79 | 0,74 | 0,76 | 0,74 |

Comparing the values of the data of the normalized indexes, presented in Tables 4 and 6, we can state the increase in self-evaluation of STEM competencies of teachers (Fig. 4).

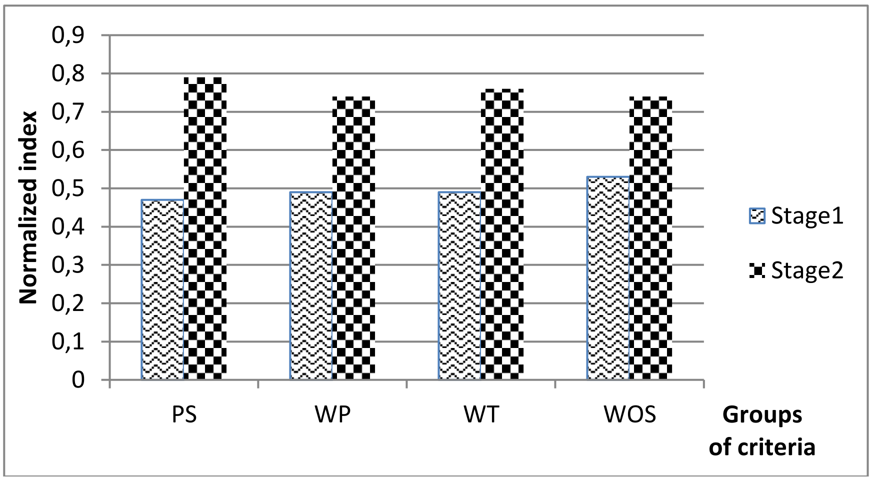


**Fig. 4.** Comparison of normalized indexes (qualifying stage, forming stage)

We used the Student's t-test to identify statistical differences between the mean values of the points given by each respondent at the qualifying and forming stages of the study.

We formulate a zero ($H_0$) and an alternative ($H_1$) hypothesis.

$H_0$ – there are no statistical differences between the mean values of the points for each of the groups of criteria (PS, WP, WT, WoS);

$H_1$ – there are statistical differences between the average values of the points for each of the groups of criteria (PS, WP, WT, WoS) obtained at the qualifying and forming stages.

The results of calculations of the Student’s t-test ($T_{emp}$) for each STEM group are shown in Table 8.

**Table 8.** Value of Student's T-test for each of the groups of criteria (forming stage)

| Criteria | PS | WP | WT | WOS |
|---|---|---|---|---|
| $T_{emp}$ | 16,3 | 12,1 | 11,1 | 10,9 |
| $T_{cr}$ ($\alpha$=0,05) | 1,99 | 1,99 | 1,99 | 1,99 |
| $T_{cr}$ ($\alpha$=0,01) | 2,65 | 2,65 | 2,65 | 2,65 |

The obtained empirical values of the Student's t-test for all groups of criteria are in the significance zone. Therefore, we adopt the alternative hypothesis (H1), which confirms the effectiveness of the proposed lifelong learning model, professional training and retraining of teachers based on the development of STEM competencies of practicing teachers.

## 3 Conclusions

The results of the conducted scientific research on the qualifying stage indicate that many practicing teachers are interested in STEM education, but do not believe that they have sufficiently well-developed STEM competencies.

During the exploratory stage of our study, we have developed the model of lifelong learning, the model for professional retraining of teachers for the development of their STEM competencies, including the definition of diagnostic goals of STEM disciplines. Among them are development of the model of STEM competencies; formulation of learning outcomes of STEM disciplines; content of educational projects; organizational forms of training; training methods; training means; results of training upon the project.

The developed model of STEM competencies for professional teacher training and lifelong learning includes four components (Problem solving, Working with people, Work with technology, Work with organizational system), which are divided into three domains of STEM competencies: Skills, Knowledge, Work activities.

The statistical processing of research data allows us to make a scientifically substantiated conclusion about the effectiveness of the proposed model of lifelong learning, professional training and retraining of teachers based on the development of STEM competencies of practicing teachers.

Further research and discussion is needed on the implementation of a comprehensive education policy in the field of lifelong Learning and STEM, the ability of teachers to broadcast advanced STEM competencies and prepare young people for their future STEM career.

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