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Strategies for development of STEM competencies of new generation future specialists

In the rapidly changing landscape of the 21st century, proficiency in Science, Technology, Engineering, and Mathematics (STEM) has become essential for the future workforce. This research focuses on examining the development of STEM competencies in upcoming professionals through effective approaches, specifically the inquiry-based learning (IBL) strategy. The investigation delves into successful strategies for cultivating STEM skills in the next generation of experts, highlighting the significance of inquiry-based teaching strategy. The paper also examines the role of students and educators in creating an environment conducive to STEM competency development. By aligning educational practices with the demands of the modern workforce, these strategies aim to produce adaptable, innovative, and skilled professionals capable of addressing global challenges and driving sustainable progress. This program demonstrates how inquiry-based learning method can effectively impact on the new generation of future specialists. The study emphasizes the importance of an inquiry-based learning strategy for the development of STEM competencies, which enhances educators' and students' practical skills as well as their readiness to study and assume personal accountability for their education. The findings demonstrated that by enhancing their STEM knowledge and competencies, the IBL strategy program benefited both educators and students.

Keywords: STEM competencies, IBL strategy program, key strategies, development, students, educators, future specialists of new generation, educational practice.

Introduction

The term "STEM" has evolved into a foundational competency based on interdisciplinary knowledge of its founding disciplines, characterized by the capacity for innovative thinking and the ability to design and implement effective solutions.

STEM competence is characterized by the capacity to integrate different knowledge, skills and abilities to identify and solve problems typical for the domain across a wider range of contexts [1].

STEM competence refers to an individual's ability to apply STEM knowledge, skills, and attitude appropriately in everyday life, the workplace, or educational context [2].

STEM competencies have been defined as the integration of knowledge, skills, and dispositions that enable individuals to solve problems, think critically, and innovate within and across STEM disciplines.

The model of the STEM competency paradigm that is being presented according to H. Jang [3]. The 37 criteria are divided into three domains: work activities, knowledge, and skills. The three core STEM competency areas — skills, knowledge, and work activities — were organized into the following categories, each encompassing a substantial number of specific criteria: problem solving (PS), working with people (WP), working with technology (WT), and working with organizational systems (WoS) (Table 1).

Table 1

Framework of STEM competencies

Domain	**Problem Solving**	**Working with People**	**Work with Technology**	**Work with Organizational System**
Skills	Critical thinking, Complex problem solving, Creative thinking	Communication skills, Ability to work in team, Social intelligence, Emotional intelligence	Installation of equipment, Programming (Network & System Administration)	Systems analysis, Systems Evaluation, Decision making

Continuation of Table 1

Domain	**Problem Solving**	**Working with People**	**Work with Technology**	**Work with Organizational System**
Knowledge	English language, Mathematics, Computers and Electronics, Engineering and Technology, Administration and Management, Customer and personal service, Education and training	Knowledge of regularities, principles and methods of teaching, Assessment of learning outcomes, Getting feedback, Knowledge of leadership technologies, Knowledge of teamwork techniques	Computer Science, Basics of microelectronics	Knowledge of management principles
Work Activities	Getting information, Evaluation of information, Making decisions and Solving problems, Coordinating the Work and Activities of others	Developing and Building Teams, Providing Consultation and Advice to others, Coaching and Developing others, Guiding, Directing and Motivating Subordinates	Interacting with Computers, Analyzing Data and Information, Judging the Qualities of Things, Services, or People	Developing Objectives and Strategies, Monitoring Processes, Materials, or Surroundings, Compliance with Standards
Stem Competencies	Problem solving skills	Communication skills	Technological and engineering skills	System skills, resource management skills

The rapid advancement of technology and the growing demand for innovative solutions have elevated the importance of STEM (Science, Technology, Engineering, and Mathematics) education in preparing future specialists for a dynamic and complex global landscape. The current era is characterized by swift technological progress, increased global interconnectedness, and a constantly changing employment landscape, all of which necessitate a workforce proficient in advanced STEM (Science, Technology, Engineering, and Mathematics) skills. These disciplines are crucial for driving innovation, economic growth, and addressing complex worldwide issues such as climate change, healthcare, and technological transformation. As industries increasingly depend on STEM-based solutions, developing expertise in these areas has become a top priority for educators, policymakers, and industry leaders. While STEM education has gained national attention as an effective means of cultivating essential 21st-century skills, current approaches have not yielded the desired outcomes. The primary reason for this shortfall is the lack of a clear and structured explanation of effective strategies for developing STEM competencies.

The next generation of professionals must not only possess technical knowledge but also exhibit creativity, critical thinking, problem-solving abilities, and adaptability. Traditional educational methods are no longer adequate to meet the diverse and dynamic requirements of the STEM workforce. This calls for a shift towards innovative strategies that promote interdisciplinary learning, hands-on experiences, and collaboration with industry stakeholders. By integrating cutting-edge technologies, real-world applications, and personalized learning paths, educators can empower students to become proactive contributors to the global economy and society.

STEM education has garnered nationwide focus as an effective approach for developing essential competencies for future talents. Despite this recognition, current STEM educational practices have not achieved the intended outcomes. The primary issue lies in the absence of a clear and structured explanation of what strategies are effective in the development of STEM competencies.

Furthermore, studies have indicated that integrated education in science, technology, engineering, and mathematics (collectively referred to as STEM) is fundamental to preparing individuals who are both knowledgeable and technologically proficient. [4]. As a result, STEM education has received increased attention and interest in recent years, with interest in STEM design models exploding across the educational landscape, leading to curriculum redesign through STEM initiatives. In these models, the role of future professionals in the next generation is one of the most important factors in ensuring excellence in STEM education [5]. Future professionals proficient in STEM must demonstrate both a deep knowledge of STEM subject content and mastery of all the necessary skills and competencies. As a result, the professional development of future professionals is critical to the development and implementation of STEM education concepts and programs [6].

Consequently, this paper explores strategies for developing STEM competencies in the future specialists of new generation. This study emphasizes the significance of inquiry-based learning strategy for developing of STEM competencies of future professionals.

Researchers have explored various strategies for fostering these competencies addressing both theoretical and practical approaches (Table 2). This literature review highlights key strategies identified in scholarly research and their implications for educational practices.

Table 2

Strategies for the development of STEM competencies

Strategy	Brief description	Exemplary References
Inquiry-based learning (IBL)	A student-centered approach focusing on the asking of questions, critical thinking, and problem solving, enables students to develop skills needed throughout their whole lives. As such, it helps students to cope with their problems	(Tseng, Tuan, & Chin, 2012) [7].
Project-based learning (PjBL)	A student-centred form of instruction which is based on three constructivist principles: learning is context-specific, learners are involved actively in the learning process and they achieve their goals through social interactions and the sharing of knowledge and understanding	(Cocco, 2006) [8].
Problem-based learning (PBL)	An instructional method in which students learn through facilitated problem solving that centers on a complex problem that does not have a single correct answer	(Hmelo-Silver, 2004) [9].
Cross-Disciplinary Approaches	The social character of cross-disciplinary science is clear — it is conducted by diverse people who must interact, make decisions, and take collective action	(Magnus, 2007) [10].
Use of Technology	The use of technology includes not only machines (computer hardware) and instruments, but also involves structured relations with other humans, machines, and the environment	(Isman, 2012) [11].

In this Table, we present examples of strategies that are revolutionizing education worldwide, bridging the gap between theoretical knowledge and real-world application.

Above-described approaches like project-based, problem-based, cross-disciplinary, use of technology and inquiry-based learning strategies play a crucial role in developing the skills and competencies in STEM fields and guide future specialists in the digital learning environments. This study demonstrates how these effective strategies can harness technological advantages to further expand educational possibilities. We suggest that professionals can enhance their subject knowledge in an engaging manner within these contexts, while simultaneously developing STEM knowledge and competencies. Overall, we emphasize an inquiry-based learning (IBL) strategy that taps into future specialists' inherent motivation, effort, and resilience. We argue that by participating in the program outlined in this work, future specialists will develop a stronger sense of their own agency, which can have significant, transferable effects on their ongoing learning experiences and life and career goals.

Inquiry-Based Learning (IBL) is a student-centered educational approach that emphasizes active engagement and critical thinking. In IBL, students are encouraged to ask questions, investigate problems, and develop solutions through exploration and research. This method contrasts with traditional instruction, where teachers primarily deliver factual information. Instead, IBL positions students as active participants in their learning journey, fostering deeper understanding and retention of knowledge.

According to Yang (2013), to enhance students' employability after graduation, practice-oriented courses should be designed to meet industry demands and societal expectations. The course content should focus on developing students' professional qualities and innovative abilities. This approach allows educational institutions to bridge the gap between education and employment, resulting in improved educational and economic outcomes [12].

Regarding the enhancement of STEM education, researchers have advocated for the use of inquiry-based teaching methods to encourage technological exploration, elevate teaching practices, and bolster the effectiveness of STEM instruction [13, 14, 15, 16].

An examination of scientific and educational literature on the topic has revealed multiple aspects of training specialists for the new era. Various researchers have suggested that higher education institutions should strengthen industry-academia partnerships, provide practice-oriented courses, and enhance educators' practical skills by improving their communication abilities to effectively address the gap between theoretical knowledge and practical application [17, 18, 19, 20, 21, 22]. So, based on these conducted researchers we decided to choose IBL strategy as the most effective method in the development of STEM competencies.

The Inquiry-Based Learning (IBL) strategy program for developing STEM competencies among Computer Science (CS) students and educators was structured around problem-solving, project-based learning, and industry collaboration. The curriculum integrated real-world challenges, coding projects, AI and data science applications, and interdisciplinary teamwork to enhance critical thinking and technical proficiency. Implementation involved interactive workshops, hands-on labs, mentorship programs, and industry partnerships, ensuring alignment with current technological trends. Educators were trained in student-centered teaching methodologies, fostering a research-driven learning environment. The program was assessed through self-evaluations and competency-based assessments, demonstrating significant improvement in STEM knowledge, creativity, and problem-solving skills.

Methods and materials

The following phases were involved in the development of an IBL program strategy based on the growth of STEM competencies at Karaganda Buketov University, which is based on the faculty of Mathematics and Information Technology: designing, constructive, analytical, and corrective. Strategic, conceptual, and functional analysis were all part of the designing process. The formulation of broad goals for future experts' professional retraining based on the growth of their STEM competencies was taken into consideration by strategic analysis. The theoretical underpinnings of STEM abilities were identified at the conceptual analysis level. Functional analysis made it possible to find useful initiatives and ascertain the substance of STEM-oriented work.

To evaluate the efficacy of the IBL program strategy for STEM competency development, we carried out an analytical-adjustment stage pilot study and One-Sample Kolmogorov Smirnov Test.

Results and discussion

The Inquiry-Based Learning (IBL) strategy program was provided by the independent work of Computer Science (CS) students and educators at the Karaganda Buketov University over the course of the 12-week semester 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. This program consists of 3 phases: 1) Exploration & Problem Identification (Weeks 1–3); 2) Experimentation and Problem-Solving (Weeks 4–8); 3) Reflection and Real-World Application (Weeks 9–12).

This program for developing STEM competencies among Computer Science (CS) students and educators was structured around problem-solving, project-based learning, and industry collaboration. The curriculum integrated real-world challenges, coding projects, AI and data science applications, and interdisciplinary teamwork to enhance critical thinking and technical proficiency. Implementation involved interactive workshops, hands-on labs, mentorship programs, and industry partnerships, ensuring alignment with current technological trends. Educators were trained in student-centered teaching methodologies, fostering a research-driven learning environment. The program was assessed through self-evaluations and competency-based assessments, demonstrating significant improvement in STEM knowledge, creativity, and problem-solving skills.

32 practicing educators and 24 (CS) students were the participants of the experiment. The H. Jang model is the foundation of the STEM competency paradigm that is being presented. The 37 requirements are divided into three domains: work activities, knowledge, and skills. Universities are the outcome of the criteria selection process. We recommended educators and students to assess their level of STEM competency development at the initial (diagnostic) stage. The assessment was conducted using a 5-point Likert-type scale in accordance with the standards put forth by H. Jang.

We divided the 37 primary criteria — which were spread over the three STEM competency areas of skills, knowledge, and work activities — among the substantial number of criteria: problem solving (PS); working with people (WP); working with technology (WT); working with organizational system (WoS) were the categories into which each area consolidated the criteria, as outlined in Table 1.

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 Responders	**Points by respondent**			
	PS	**WP**	**WT**	**WOS**
1	0,53	0,35	0,41	0,29
2	0,39	0,40	0,47	0,51
…				
56	0,55	0,58	0,66	0,51

The average score generated by respondents through self-evaluation of all 37 questions served as a latent measure of STEM competency development. The normalized index In resulted from calculating the ratio.

$$I_n = \frac{s_i - N}{s_{max} - N}$$

Where “s_i” represents total points by respondent “i”, “s_{max}” denotes 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 (Diagnostic Stage)

	PS	**WP**	**WT**	**WOS**
Normalized index	0,47	0,49	0,43	0,53

The development stage of STEM competencies revealed itself as a latent indicator through scale-based evaluation. This paper uses a scale of importance (0-1) based on normalized values from the ONET database, the official information system of the US Department of Labor. A similar gradation was also used in the study by H. Jang (2015) to identify key competencies in STEM professions based on ONET. The scale is interpreted as follows:

- 0 — 0.24 — critical;
- 0.25 — 0.49 — low;
- 0.5 — 0.74 — sufficient;
- 0.75 — 1.0 — high

The initial study results demonstrate that students and educators possess low STEM competency levels according to self-assessment data. We evaluated the normality of each sample distribution from Table 3 to select an appropriate statistical method for processing study results. Table 5 displays the One-Sample Kolmogorov Smirnov Test results for normality and Figure 1 illustrates the distribution graphically. This test is a non-parametric statistical test used to determine whether a given sample follows a specified probability distribution (e.g., normal, uniform, exponential).

Table 5

Checking the results for the normality of each of the samples (diagnostic stage)

		PS	**WP**	**WT**	**WOS**
Normal Parameters	Mean Std.	2,8791	2,9713	3,0191	3,0806
	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

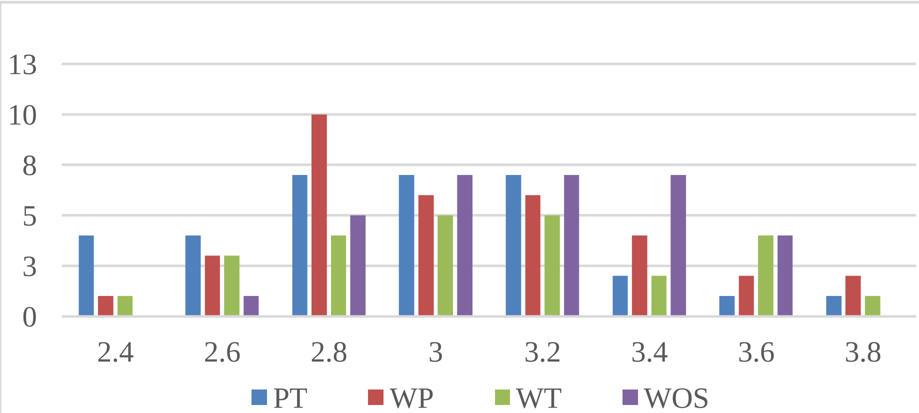

Figure 1. The grouping of respondents according to the average of diagnostic criteria values demonstrates the distribution.

The combination of tabular data and distribution graphs enables us to confirm that the samples follow a normal distribution pattern. Our inquiry-based learning strategy program enabled us to develop STEM competencies for both students and educators during the second formative stage of the study's implementation phase. The program trained university experimental groups of practicing students and educators through hands-on projects while also providing industry mentorship and collaborative research opportunities so participants could explore new technologies to develop innovative solutions and practice applying Computer Science to interdisciplinary STEM problems. Students and educators reassessed their STEM competency components during the third summative phase. At this stage the data samples showed a normal distribution according to Table 6 and Figure 2.

Table 6

Checking the results for the normality of each sample (formative stage)

		PS	WP	WT	WOS
Normal Parameters	Mean Std.	4,0214	3,9391	4,0162	3,9531
	Deviation	0,26563	0,31254	0,40712	0,37995
Most Extreme Differences	Absolute	0,131	0,119	0,141	0,080
	Positive	0,133	0,116	0,075	0,070
	Negative	-0,067	-0,090	-0,113	-0,054
Test Asymp.		0,143	0,129	0,145	0,088
Sig. (2-tailed)		0,178	0,200	0,103	0,200

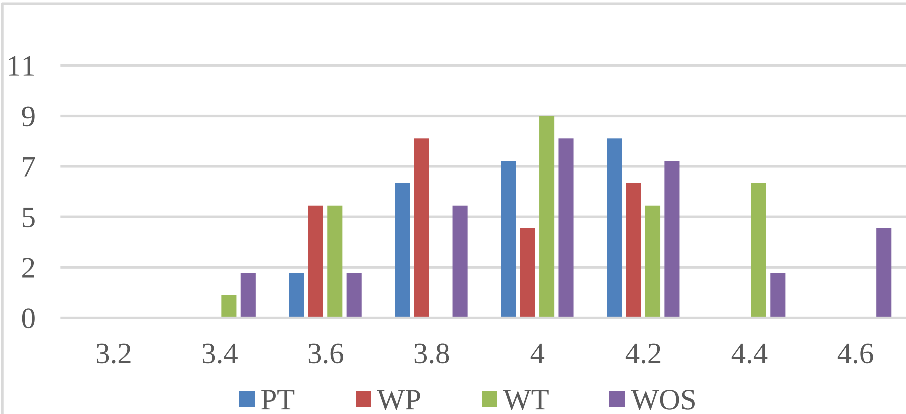

Figure 2. Distribution of respondents by the mean value of groups of criteria (formative stage)

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

Table 7

Normalized indexes of criteria groups (formative stage)

	PS	WP	WT	WOS
Normalized index	0,78	0,76	0,84	0,73

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 students and educators (Figure 3).

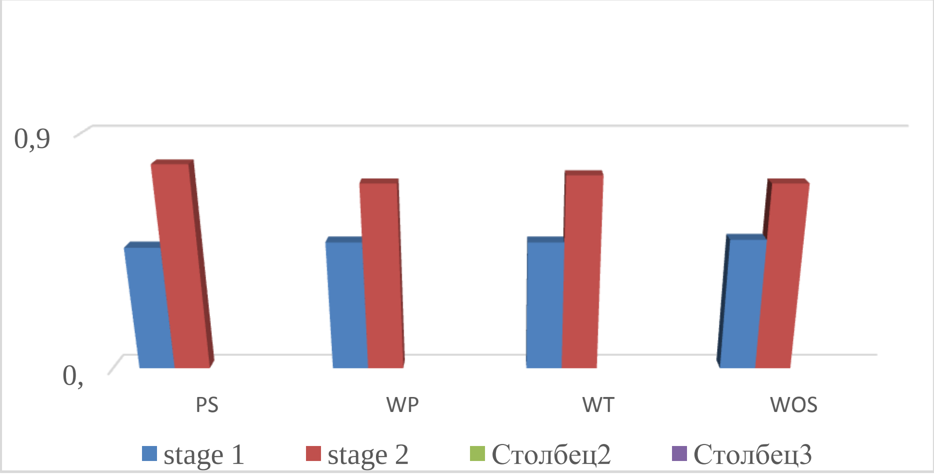

Figure 3. Comparison of normalized indexes (diagnostic stage, formative stage)

This comparison figure demonstrates us before and after outcomes of our experimental work which confirms the effectiveness of the proposed IBL strategy program for CS students and educators based on the development of STEM competencies of practicing future specialists of new generation.

Conclusion

This study aimed to investigate how inquiry-based learning strategy can enhance STEM competencies amomg future new-generation specialists. This study implemented an IBL strategy program to promote knowledge-action integration in higher education and advance STEM academic performance for both students and educators through industry-academy practice. Both students and educators responded to the program with positive and affirmative feedback. Positive changes were seen both in practical exploration abilities and among students becoming more willing to learn and manage their own educational experience. The study concluded that practical exploration training effectively develops STEM skills in new generation specialists. This research suggests that educational institutions should expand the implementation of inquiry-based teaching methods.

Thus, STEM education aims to increase learning motivation among future specialists in STEM subjects while enhancing STEM literacy and teaching students how to apply STEM knowledge for solving real-world problems. The foundation of national economic progress lies in science and technology human resources which requires future professionals to receive encouragement to enter STEM fields and obtain support to enhance their academic success in science, technology, engineering and mathematics as this will largely contribute to economic growth and global competitiveness.

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Жаңа буын болашақ мамандарының STEM-құзыреттіліктерін дамыту стратегиялары

Қазіргі қарқынды дамып келе жатқан XXI ғасырда ғылым, технология, инженерия және математика (STEM) салаларында құзыреттілік болашақ жұмыс күші үшін аса маңызды. Бұл зерттеу болашақ мамандардың STEM-құзыреттіліктерін дамытуға бағытталған тиімді тәсілдерді, атап айтқанда, зерттеуге негізделген оқыту (IBL) әдісін зерттеуге арналған. Зерттеу STEM-құзыреттіліктерін дамытуға арналған табысты стратегияларды қарастырып, зерттеуге негізделген оқыту стратегиясының маңыздылығын көрсетеді. Мақалада сонымен қатар, STEM-құзыреттіліктерін дамытуға қолайлы орта қалыптастырудағы студенттер мен оқытушылардың рөлі қарастырылған. Білім беру тәжірибелерін қазіргі еңбек нарығының талаптарына сәйкестендіру арқылы бұл стратегиялар икемді, жаңашыл және жоғары білікті мамандарды дайындауға бағытталған. Бұл бағдарлама зерттеуге негізделген оқыту әдісінің болашақ мамандардың жаңа буынына тиімді әсер ете алатынын көрсетеді. Зерттеу STEM-құзыреттіліктерін дамыту үшін зерттеуге негізделген оқыту стратегиясының маңыздылығын атап көрсетеді, бұл оқытушылар мен студенттердің тәжірибелік дағдыларын жақсартып қана қоймай, олардың оқуға деген дайындығы мен білім алу жауапкершілігін арттырады. Зерттеу нәтижелері STEM-білімдері мен құзыреттіліктерін арттыру арқылы IBL стратегиясы бағдарламасы оқытушылар мен студенттер үшін пайдалы болғанын көрсетті.

Кілт сөздер: STEM-құзыреттіліктері, IBL стратегиялық бағдарламасы, негізгі стратегиялар, дамыту, студенттер, оқытушылар, жаңа буын болашақ мамандары, оқу практикасы.

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Стратегии развития STEM-компетенций будущих специалистов нового поколения

В современном, быстро развивающемся мире XXI века владение наукой, технологиями, инженерией и математикой (STEM) становится необходимым условием для будущей рабочей силы. Данное исследование посвящено изучению развития STEM-компетенций у будущих специалистов с помощью эффективных подходов, в частности метода обучения, основанного на исследовании (IBL). В работе рассматриваются успешные стратегии формирования STEM-навыков у нового поколения специалистов, подчеркивая значимость исследовательского подхода в образовательном процессе. В статье также анализируется роль студентов и преподавателей в создании среды, способствующей развитию STEM-компетенций. Выравнивая образовательные практики в соответствии с требованиями современного рынка труда, предложенные стратегии направлены на подготовку адаптивных, инновационных и квалифицированных специалистов, способных решать глобальные проблемы и способствовать устойчивому развитию. Программа демонстрирует, как метод исследовательского обучения может эффективно влиять на формирование нового поколения специалистов. Исследование подчеркивает важность исследовательской стратегии обучения для развития STEM-компетенций, что не только улучшает практические навыки преподавателей и студентов, но и повышает их готовность к обучению, а также личную ответственность за образование. Полученные результаты показали, что программа стратегии IBL оказалась полезной как для преподавателей, так и для студентов, способствуя развитию их STEM-знаний и компетенций.

Ключевые слова: STEM-компетенции, стратегическая программа IBL, основные стратегий, развитие, студенты, преподаватели, будущие специалисты нового поколения, учебная практика.

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