3.1. Prospects for the Use of STEM Education in the Professional Training of Future Primary School Teachers

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Abstract. *The study examines the feasibility of integrating STEM education (science, technology, engineering, and mathematics) into the training system for future primary school teachers. The relevance of the research is determined by the need to develop new competencies among teachers that meet the challenges of the technological era and the goals of the New Ukrainian School (NUS) educational reform. The paper analyzes scientific approaches to defining STEM competence of a primary school teacher, whose structure comprises cognitive, operational, motivational, and reflective components, as well as organizational and methodological conditions for its development in higher education institutions, including the creation of a STEM-oriented learning environment, implementation of integrated courses, and engagement in project-based learning.*

The empirical study was conducted at Uzhhorod National University and included a two-stage survey of 45 pre-service primary school teachers (27 bachelor's and 18 master's students) before and after the introduction of STEM elements into the curriculum. The results demonstrated a statistically significant improvement in students' readiness to implement innovative teaching methods, with the average stem readiness index increasing from 59% to 69%. Positive changes were observed in knowledge, motivation, and self-efficacy, with the greatest progress shown by students with lower initial levels. A moderately positive correlation was found between pre- and post-test results ($r \approx 0.46$), indicating a partial dependence on prior preparation and the effectiveness of the pedagogical intervention.

It was concluded that STEM-oriented training constitutes a promising pathway toward the modernization of teacher education. Integrating STEM technologies into university courses, equipping laboratories, and engaging students in project and research activities enhances the quality of professional training, fosters innovative thinking and interdisciplinary collaboration skills, and readiness to utilize contemporary educational tools and methods. The findings

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may serve as a methodological foundation for designing educational programs that prepare teachers of a new generation.

***Keywords**: STEM education, teacher training, primary school, STEM competence, innovative teaching technologies, pedagogical experiment.*

Introduction

Global challenges of recent years, including epidemics, natural disasters, and military conflicts, have accelerated the digitalization of educational services. During the war, Ukrainian education shifted to distance and blended learning formats. The adoption of an integrated learning approach has significantly transformed the requirements for knowledge and competencies among all participants in the educational process. Innovative competence has become a professional necessity for a new generation of teachers capable of working effectively in a rapidly changing world, marked by technological advancements and social shifts. Consequently, STEM education (Science, Technology, Engineering, Mathematics) has gained increasing recognition in many countries.

In realizing the potential of STEM education, the role of the primary school teacher is crucial, as it is at this level that learners first encounter scientific and technological ways of understanding the world. Therefore, modern teachers must not only possess subject knowledge but also be able to integrate different fields, apply innovative teaching methods, and use advanced technologies in instruction. This creates the need for change in the system of professional teacher training.

This study substantiates the prospects for using STEM education in the preparation of future primary school teachers, taking into account both international experience and the realities of Ukrainian higher education. It also presents the results of an empirical study on the effectiveness of STEM-oriented learning among students of pedagogical specialities.

Analysis of current research

In contemporary academic literature, STEM education is viewed as a modern educational paradigm grounded in the integration of natural sciences, mathematics, and technology (including information and communication technologies) to address pressing issues of educational development. The core idea of STEM education is to strengthen the scientific and technological dimension of learning, create conditions for developing students' creativity, and enhance teachers' professional competence (Zorochkina & Zdir, 2024). Research emphasizes that STEM education aims to develop a holistic system of knowledge, skills, and modes of thinking, while also fostering research abilities, an engineering approach to problem-solving, critical thinking, and creativity.

The STEM (Science, Technology, Engineering, Mathematics) concept is becoming increasingly widespread worldwide, as the integration of scientific and technical disciplines with creative elements substantially improves the quality of professional training (Molnar, 2023). STEM education represents a forward-looking model for curriculum design, one that integrates various disciplines in an interdisciplinary manner. Its principal goal is to modernize educational content in line with contemporary demands, strengthening the scientific and technical orientation of instruction, fostering youth creativity, and improving teachers' professional competence. STEM-based learning develops competent, creative, and innovation-oriented individuals ready to face the challenges of modern society. The key competencies of the New Ukrainian School (NUS) align naturally with the structure of STEM education, forming a foundation for learners' successful personal and professional growth (Zorochkina & Zdir, 2024).

Accordingly, a modern teacher must possess STEM competence, a dynamic combination of knowledge, skills, values, and personal qualities that enable innovative work and the effective implementation of STEM methodologies in the educational process. Zorochkina and Zdir (2024) define the structure of STEM competence for future primary school teachers as comprising cognitive, operational, personal-motivational, and reflective components. Developing these components requires a deliberately structured educational process in higher education institutions. Effective approaches include engaging students in practical and research activities, completing STEM projects, mastering key STEM concepts within professional methodology courses or specialized disciplines, using active and technology-based teaching methods, and creating a STEM-oriented learning environment.

An essential condition for the successful integration of STEM components into teacher education is the modernization of the organizational and methodological foundations of the instructional process. As O. Kuzenko (2021) emphasizes, updating the methodological support for teacher preparation should lead to the emergence of an "educator of a new generation," whose defining characteristic is the ability to apply innovative pedagogical technologies. A contemporary teacher must be free from outdated stereotypes and capable of creating a learning environment that fosters both effective instruction and the development of a child's creative potential. The content, forms, and methods of teacher training should be oriented toward cultivating the ability to overcome innovation barriers, define pedagogical goals, achieve them through the use of modern educational technologies, and continuously engage in professional growth (Kuzenko, 2021).

In Ukraine, this issue has particular significance in light of the New Ukrainian School reform and the country's integration into the European educational sphere, both of which impose higher standards on teacher education. As O. Akimova (2024) notes, the teacher of the New Ukrainian School must simultaneously act as a tutor, facilitator, and researcher, while being proficient in information and communication technologies and foreign languages.

Within the broader development of STEM education, the experience of teacher preparation in Canada offers particularly instructive examples. According to Johnson, Walton, and Breiner (2020), the implementation of STEM education in teacher training falls under provincial jurisdiction, yet a shared vision of strategic priorities has been established at the national level. The Council of Ministers of Education, Canada (CMEC), identifies STEM education as one of the main priorities for advancing educational programs across the country.

This has translated into tangible policy reforms. For instance, in Ontario, a revised Science & Technology curriculum introduced in 2022 mandates the study of coding fundamentals and engineering design beginning in Grade 1 (Ontario Ministry of Education, 2022). Such measures reflect a global trend toward modernizing teacher education to meet the demands of a STEM-oriented society.

The Canadian higher education sector in pedagogy actively experiments with institutional models of STEM training. Specialized programs have been introduced, for example, the B.Ed. (Secondary) The STEM one-year program at Thompson Rivers University prepares teachers of integrated natural sciences and mathematics with a strong emphasis on engineering and technology (Thompson Rivers University, 2022).

Another approach involves creating STEM-oriented learning environments within traditional teacher education programs. For instance, the Faculty of Education at the University of Ottawa established the edstudiO laboratory, equipped with 3D printers, robotics kits, and other innovative tools. In this space, pre-service teachers learn to design lessons based on experimentation and play (University of Ottawa, 2024). As a result, graduates of Canadian teacher preparation programs demonstrate a high level of readiness to integrate modern technologies and online resources into their professional practice, a model that can serve as a benchmark for Ukrainian teacher education under current conditions.

Equally noteworthy is Canada's experience in post-graduate teacher education, where a well-developed system of continuous professional development for STEM educators has been established. This system ranges from regular training sessions organized by local school boards to nationwide initiatives such as the Let's Talk Science program, which offers webinars, summer institutes, and online courses aimed at enhancing teachers' STEM-related skills (Innovation, Science and Economic Development Canada, 2021).

Importantly, participation in high-quality STEM training has a measurable effect on teacher motivation. According to Allen and Sims (2017), the likelihood of STEM teachers remaining in the profession increases by 160% among those who engage in ongoing professional development. Implementing similar mechanisms in Ukraine through mentorship systems, partnerships between schools and universities, and flexible professional learning formats could ensure both sustainability and effectiveness in advancing STEM education.

Thus, the Canadian experience of teacher preparation provides valuable insights that can be adapted to the Ukrainian educational landscape through a three-tiered model of STEM implementation:

(1) National level – recognition of STEM education as a strategic priority for educational development;

(2) Regional level – institutionalized integration of STEM into school and teacher education programs;

(3) Institutional level – combining theoretical understanding of STEM with the practical development of STEM competencies in an interdisciplinary learning environment.

Ukrainian scholars also acknowledge the importance of incorporating STEM education into teacher training. H. Klimashevska (2024) demonstrates the positive impact of STEM education on the development of innovative thinking and creative abilities in future teachers. She recommends that pedagogical universities, in alignment with Ukraine's integration into the European educational space, enrich their teacher training curricula with specialized methodologies that foster creativity in both classroom learning and independent work, as well as teaching practice. Similarly, O. Karpenko (2024) emphasizes the need to introduce compulsory courses on STEM education covering its principles, technologies, and tools within higher pedagogical institutions and professional development programs. This, in her view, would strengthen teachers' readiness to apply innovative instructional technologies in practice.

A. Diachenko and Kh.-M. Popyuk (2021) investigated teacher preparation for teaching the integrated course Design and Technologies in primary school. They concluded that such preparation is inherently multifaceted and includes mastering pedagogical technologies of learner-centered and competence-based instruction, acquiring technical and technological knowledge and skills, learning new teaching methods (such as game-based and project-based learning), and developing the ability to integrate design and visual arts concepts into other educational fields. Importantly, as the authors emphasize, design education is inherently interdisciplinary. It synthesizes technology and art. Therefore, future teachers must master the fundamentals of design (including composition, color theory, and related principles) to apply them effectively across various subjects.

Overall, the analysis of Ukrainian academic sources demonstrates that integrating STEM education into the professional preparation of primary school teachers is a multifaceted task. First, there is a need to clearly define the content of teachers' STEM competence and the pathways for its development during university training. Second, it is necessary to modernize curricula and academic programs by introducing specialized STEM modules, project-based and research tasks, and elective courses that equip students with practical skills in applying interdisciplinary approaches. Third, creating an appropriate instructional and methodological environment is crucial. This involves establishing the necessary material and technical infrastructure (laboratories, equipment, and software), as well as developing textbooks and methodological guidelines to help instructors integrate STEM technologies into pedagogical disciplines (Molnar, 2023).

A strong base of innovative experience is already taking shape: numerous collections and manuals on implementing STEM education have been published, while electronic resources and online platforms are being actively introduced. These enable students and instructors to use modern tools such as web-based services and virtual laboratories (Molnar, 2023). Pedagogical universities should demonstrate institutional readiness and commitment to these innovations by conducting interactive sessions focused on developing STEM-related skills among future teachers (Molnar, 2023).

Leading international studies underline that the effective implementation of STEM education in teacher preparation requires a systematic and comprehensive approach. An analysis of publications from 2019 to 2024 reveals a global trend toward integrating STEM disciplines into teacher education curricula, establishing STEM laboratories and project modules, and developing students' interdisciplinary competencies (Thanh et al., 2025). For example, in China, the government has initiated numerous Teacher Professional Development (TPD) programs that emphasize interdisciplinarity, curriculum renewal, and the enhancement of teachers’ technological proficiency. Reviews of these projects indicate that Chinese TPD initiatives focus on creating integrated courses, expanding the practical component of instruction, and promoting the use of modern ICT tools. Many of these training programs have gradually adopted blended or fully online formats (Rehman et al., 2025). This aligns with broader global initiatives: in both the United States and Europe, it is widely acknowledged that preparing next-generation teachers must extend beyond discrete subject instruction to include practical STEM projects, the development of critical thinking, and collaborative practices (Thanh et al., 2025).

A vital component of teacher education programs is the inclusion of project-based activities. Researchers have observed that working on real-world projects that incorporate science, technology, engineering, and mathematics (STEM) significantly enhances pre-service teachers’ motivation and confidence in their own abilities. A study conducted in Turkey found that participation in STEM-design courses where students develop a project from concept to implementation substantially improved pre-service teachers’ self-efficacy in the STEM field (Elmali & Kiyici, 2025). However, novice teachers often encounter difficulties distinguishing between the engineering and technological components of their projects, highlighting the need for additional instruction focused on these specific elements of STEM.

A similar emphasis on project-based work was observed in Israel, where groups of students collaboratively designed interdisciplinary STEM lessons that integrated two or three subject areas simultaneously. Analysis of these modules revealed that pre-service teachers tended to concentrate on individual tasks while neglecting the development of collaborative skills (Anabousy & Daher, 2022). Such findings highlight the need for providing targeted instructional support during project-based learning, including direct facilitation and mentoring that aim to strengthen teamwork and creative thinking abilities. Consequently, many international programs include STEM laboratories and makerspaces where students can test their projects under faculty supervision, fostering creativity and innovation-oriented competencies.

In global STEM pedagogy, considerable attention is given to developing specialized STEM competencies among future teachers, a comprehensive combination of knowledge, skills, and values that enables effective integration of STEM methods into the educational process. International programs employ active learning techniques such as practical workshops, case-based learning, online laboratories, and project or research assignments implemented in real or simulated learning settings (Rehman et al., 2025; Anabousy & Daher, 2022). This approach cultivates critical thinking, collaboration skills, and proficiency in using modern technological tools (P21 Partnership, 2019; Elmali & Kiyici, 2025). For instance, partners in Israeli programs emphasize that projects should include research and analytical stages, promote data-based reasoning, and foster scientific modes of inquiry and evidence-based decision-making.

Engaging students in project-based and interdisciplinary activities increases their motivation and confidence (Elmali & Kiyici, 2025). At the same time, major differences between international and Ukrainian contexts lie in scale and resource availability. While in other countries STEM laboratories and continuous teacher development programs are often supported by government initiatives or the technology industry, Ukrainian efforts are more commonly implemented through research projects and faculty-level initiatives within individual universities.

Therefore, it can be argued that both international programs and Ukrainian practice are increasingly focused on integrating courses and developing STEM competencies. In both contexts, the project-based methodology serves as a central mode of learning, encompassing instructional case studies, laboratory experiments, and interdisciplinary educational initiatives. In Ukraine, particular emphasis is placed on advancing the New Ukrainian School (NUS) reform and aligning teacher education with European standards. The innovative teacher is expected to act as a facilitator and tutor, equipped with proficiency in ICT and 21st-century skills.

International research confirms that such competencies, critical thinking, digital literacy, and creativity form the foundation of STEM education and are integral to educational development strategies in the United States, China, the European Union, and other regions (Rehman et al., 2025; Elmali & Kiyici, 2025). Globally, the need to modernize teacher preparation through practice-oriented STEM courses, interdisciplinary tasks, and continuous professional development supported by digital technologies, online training, and remote laboratories is widely recognized.

What unites Ukraine with international systems is the focus on project- and research-based learning, integrated courses, and the cultivation of innovative thinking among future teachers. The main differences lie in the scope of support and the specific instruments employed. Abroad, these efforts are typically embedded in national strategies and supported through well-funded STEM centers. In Ukraine, innovative laboratories and courses are often implemented as local initiatives within individual universities or faculties.

Modern approaches to teacher education aim to prepare future educators for life in a digital society characterized by rapid technological transformation, a goal reflected in numerous international strategies and programs. In the European Union, the Digital Education Action Plan 2021–2027 identifies the modernization of teacher preparation as a key priority for promoting digital and STEM skills among school students. The strategy highlights a shift in the teacher's role from a transmitter of knowledge to a tutor and mentor capable of organizing learning through digital tools and project-based methods (European Commission, 2023, p. 15).

The digitalization of education requires future teachers to develop strong ICT competencies. As shown by recent international studies, nearly all countries have incorporated the enhancement of teachers' digital skills into their national education strategies. Ukraine has also adopted a Digital Education Strategy, and the New Ukrainian School reform promotes IT integration as a guiding trend in teaching and learning (Ministry of Education and Science of Ukraine, 2021).

At the same time, global data reveal a significant increase in attention to STEM education at the primary level: the number of scholarly publications on STEM for younger students has increased substantially. Key topics include embedding STEM into school curricula, developing children's abilities for self-directed learning and inquiry, and encouraging the use of advanced technologies such as robotics and virtual laboratories. These developments respond to the demands of the 21st century, as societies increasingly require not isolated subject knowledge but a holistic understanding, the ability to apply mathematics and science to real-world problems, think creatively, and work collaboratively (Elmali & Kiyici, 2025).

For Ukraine, global educational challenges are being addressed through the New Ukrainian School (NUS) reform, which aims to foster creative and technologically literate citizens. The key competencies outlined in NUS research skills, critical thinking, and ICT literacy closely align with the core ideas of STEM education. According to Ukrainian experts, a modern primary school teacher must be not only a transmitter of knowledge but also a facilitator and mentor capable of organizing project-based learning and critically evaluating information. The ongoing digitalization of education, in particular, requires teachers to be ready for continuous professional growth and to regularly update their technological skills.

An analysis of scholarly sources confirms that STEM education represents a promising direction for improving teacher preparation, as it makes learning more engaging, technologically advanced, and connected to real-life applications. Pre-service teachers who participate in STEM-oriented activities during their training develop critical thinking, teamwork, problem-solving skills, and familiarity with innovative teaching methods (Molnar, 2023; Zorochkina & Zdir, 2024). These outcomes enhance their professional competence and readiness to implement innovations in schools. At the same time, existing research underscores the need for additional empirical studies to determine the optimal models and conditions for integrating STEM components into university teacher education curricula.

Strengthening the role of STEM education in higher pedagogical education corresponds with global sustainable development and 21st-century learning strategies. It broadens opportunities for integrating innovative instructional methods into primary classrooms and prepares teachers to act as creators of new ideas and technological solutions in their professional practice. Examining leading international practices helps justify national innovations such as fostering teachers' STEM competence, advancing project- and research-based learning, and updating teacher education content in line with modern professional standards.

The significance of this study lies in its applied orientation. It offers empirically grounded insights for enhancing the preparation of future teachers within the framework of STEM education. Unlike purely theoretical investigations, the findings of this research possess direct practical value and can serve as a tool for modernizing teacher education in higher pedagogical institutions. The presented results and conclusions form a scientific and methodological foundation for preparing a new type of professional and educator-researcher, innovator, and mentor capable of effectively implementing STEM principles in professional practice for the benefit of future generations.

The *purpose* of this study is to provide theoretical substantiation and experimental modeling of approaches to implementing STEM education in the professional preparation of future primary school teachers. This objective entails analyzing scientific and methodological literature on the issue, identifying the structural components of teachers' STEM competence, developing organizational and methodological approaches to fostering this competence during training, and evaluating the effectiveness of integrating STEM elements into the preparation of pre-service primary school teachers based on empirical evidence. The rationale behind this goal lies in the societal demand for educators who can apply integrative and innovative methods in teaching young learners, as well as in the presence of state-level support for STEM education development, which necessitates corresponding transformations in the content and methods of teacher education.

Research Design

To test the hypothesis regarding the positive impact of STEM-oriented learning on the professional preparation of future teachers, a two-stage survey was conducted among students enrolled in the Primary Education program (specialty A3 in Ukraine). The study employed a quasi-experimental pretest–posttest design that monitored changes in key indicators, using a pretest-posttest design without a control group.

The sample consisted of 45 students from the Primary Education program at Uzhhorod National University: 27 bachelor's students (fourth year) and 18 master's students (first year of the master's program). The choice of this sample aimed to capture different levels of teacher training bachelor's students who had already acquired foundational pedagogical knowledge and master's students who possessed practical teaching experience and a higher motivation toward innovation.

The primary data collection method was a specially designed questionnaire aimed at assessing STEM competence and related indicators among pre-service teachers. The questionnaire comprised two parts: a knowledge test and an attitudinal self-assessment scale.

The first section consisted of 15 test items that evaluated basic STEM knowledge in natural sciences, mathematical concepts, and technologies, all adapted to the primary education level. The second section included 20 Likert-scale statements (ranging from 1 – "strongly disagree" to 5 – "strongly agree") that measured participants' self-perceived readiness and attitudes toward implementing STEM methodologies in the classroom. These statements addressed aspects such as confidence in STEM knowledge, interest in integrated instruction, readiness to apply experimental methods in teaching, and the ability to use modern technological learning tools.

Based on participants' responses to the Likert-scale items, an integrated indicator, the STEM Readiness Index, was calculated to represent the overall level of competence (expressed as a percentage ranging from 0 to 100%). The index was computed by averaging the normalized results of the knowledge test (in %) and the mean score from the self-assessment scale (converted to %). Thus, the index combined both objective knowledge and subjective readiness or motivation.

At the first stage (September 2024), all participants completed an initial survey (pre-test) prior to studying elective courses that incorporated STEM modules. Baseline results, including test scores and self-assessment data, were recorded and used to calculate the initial STEM Readiness Index (Stage 1).

During the semester, STEM elements were purposefully integrated into the learning process of the experimental group. Bachelor's students, as part of the course Methods of Teaching Natural Sciences, completed a mini-project in engineering design, constructing simple devices from available materials. Master's students, meanwhile, implemented segments of STEM lessons during their teaching practice in schools using lesson plans they had developed themselves.

Additionally, four thematic workshops were organized for all participants:

– Robotics and its applications in primary education;
– Use of computer simulations for modeling natural phenomena;
– Methodology of conducting STEM field trips;
– Design of integrated STEM lessons.

Students also worked in a university laboratory equipped with computers and STEM kits (including construction and experimental materials) and gained access to an online platform containing methodological resources. At the end of the semester (second stage, December 2024), a post-test was administered using the same questionnaire.

The collected data were processed using descriptive statistics and correlation analysis. The significance of changes between the two stages was evaluated using the paired Student's t-test for dependent samples, while the relationship between pre-test and post-test results was examined using Pearson's correlation coefficient (r). Statistical analyses were performed in IBM SPSS Statistics, with a significance level set at $p < 0.05$.

Research Results

The initial survey revealed that students' readiness to implement STEM education was at a moderate level, with a mean STEM Readiness Index of 59.1% at Stage 1. This indicates that participants possessed basic knowledge and a general interest in innovation, though many still lacked confidence in their ability to apply STEM methodologies in practice. Specifically, only 22% of respondents at the beginning of the academic year fully agreed with the statement *"I am capable of organizing an integrated STEM lesson in primary school"*, while approximately 40% expressed uncertainty about their ability to do so. Fewer than one-third of the students achieved high scores on the knowledge test (over 70% correct answers). As expected, master's students demonstrated slightly higher results than bachelor's students: 65.0% versus 55.0% according to the index (see Table 1).

At Stage 2 (after the integration of STEM components into the curriculum), a clear positive trend was observed. The mean overall STEM Readiness Index increased to 69.0%, representing a 9.9 percentage point gain compared to the baseline. Improvements were recorded in 82% of participants, with 60% showing substantial growth (over 10 points) and 22% exhibiting moderate progress (5–10 points). Only a few isolated cases showed no improvement or a slight decline, likely due to subjective factors such as fatigue at the end of the semester. Statistically, the difference in mean scores between the two stages was significant ($p < 0.001$, paired t-test), confirming the effectiveness of the implemented pedagogical interventions.

Table 1. Average STEM Readiness Scores of Students at the Beginning and End of the Experiment (as a Percentage of the Maximum Score)

Student Group	*N*	*Stage 1 (M ± SD)*	*Stage 2 (M ± SD)*	*Δ (points)*
Bachelor's students (4th year)	27	55.3 ± 9.5	67.1 ± 10.4	+11.8
Master's students (1st year)	18	64.7 ± 7.8	72.2 ± 9.0	+7.5
Total sample	45	59.1 ± 10.0	69.0 ± 12.0	+9.9

The obtained results indicate a statistically reliable increase in both knowledge and self-perceived readiness to use STEM approaches in teaching. This supports the hypothesis that targeted integration of STEM-oriented activities and environments within teacher education programs enhances future educators' motivation, confidence, and competence in applying innovative instructional practices.

As shown in Table 1, at Stage 1, master's students demonstrated a higher average level of STEM readiness (≈approximately 65%) compared to bachelor's students (≈approximately 55%). This result was expected, as the master's students had already completed their initial pedagogical training and some possessed prior teaching experience. However, following the experimental instruction, the gap between the groups decreased: the bachelor's students showed substantial improvement (+11.8 points), while the master's students' increase was smaller (+7.5 points). This suggests that the integration of STEM elements, particularly for those with a lower initial level of preparedness, produces a "leveling effect." At the same time, master's students also showed measurable progress, indicating that STEM-oriented learning yields additional positive outcomes even for participants with higher baseline competencies.

To gain a deeper understanding of these changes, a scatterplot was constructed to illustrate the relationship between individual students' results at both stages (Figure 1). On the horizontal axis, the pre-test STEM Readiness Index (Stage 1) values are plotted, while the vertical axis represents post-test values (Stage 2) for each of the 45 participants. The dashed line indicates the bisector $y = x$, which corresponds to an unchanged score, allowing for a clear visual representation of individual progress relative to the baseline.

Most data points in Figure 1 are located above the "y = x" line, which indicates an overall increase in performance. It is also evident that students with relatively low initial scores (on the left side of the graph) showed the greatest improvement; their points are positioned well above the diagonal, whereas those who began with high scores remained approximately at the same strong level, with their points clustering near the diagonal.

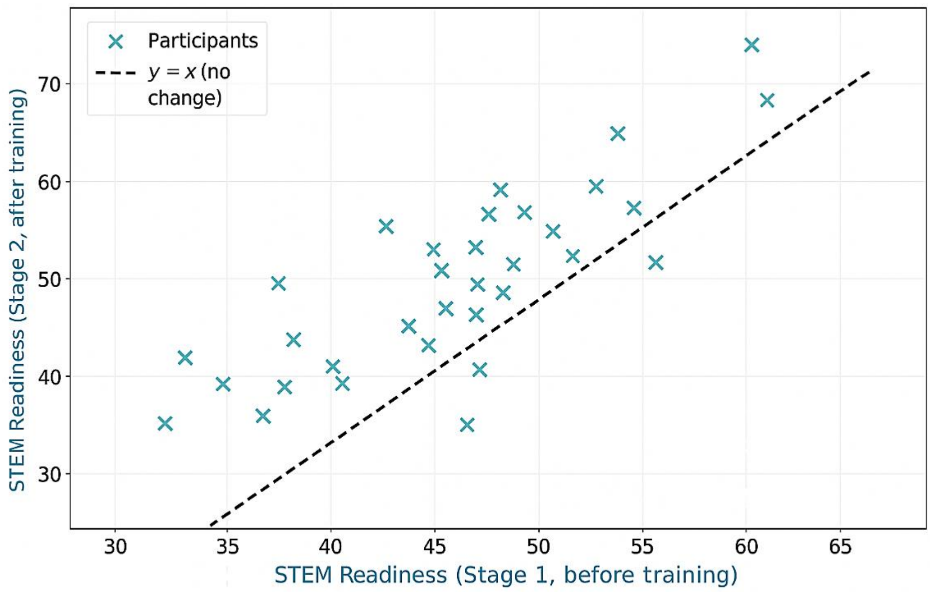

Figure 1. Relationship between students' STEM readiness before and after training

Statistical analysis revealed a moderately positive correlation between the results at the two stages, with a Pearson's correlation coefficient of $r = 0.46$ ($p < 0.01$). This suggests a moderate tendency: students who initially demonstrated stronger STEM readiness tended to maintain relatively high results after training. However, the correlation value is not very high, indicating a partial reorganization of the group under the influence of the intervention; those who started at lower levels made significant progress. Hence, the initial level of preparedness only partially determined the final outcomes.

A closer examination of the questionnaire subscales revealed that the greatest progress was made in motivation and self-confidence indicators. For instance, the proportion of respondents who fully agreed with the statement "I am excited about the idea of teaching children through the STEM approach" increased from 36% at the beginning to 67% after training. Self-efficacy also rose markedly: over 60% of students at Stage 2 rated their ability to design an integrated lesson as high, compared to only about 20% before the intervention. In the test section, performance improved notably on practical tasks. For example, while fewer than half of respondents initially identified the function of a sensor in an educational STEM kit correctly, after hands-on sessions, 80% succeeded. These findings confirm the effectiveness of practice-oriented methods: students not only assimilated theoretical concepts but also learned to use concrete technological tools, such as assembling simple electrical circuits and working with Lego Education kits.

Correlation Analysis. In addition to the previously noted relationship between baseline and final indicators, we analyzed the internal structure of STEM competence components. The correlation between knowledge test scores and self-assessed readiness at Stage 1 was $r = 0.34$ ($p < 0.05$), indicating a weak-to-moderate relationship: not all students who performed well on the test rated their readiness to implement STEM approaches highly, and vice versa. This suggests that some respondents possessed theoretical knowledge but lacked confidence in its practical application, while others were highly motivated toward innovation but had not yet acquired sufficient mastery of the subject.

After the intervention, this correlation strengthened to $r = 0.58$ ($p < 0.01$), approaching a moderately high level. This can be interpreted as follows: through practical experience, students gained a more accurate awareness of their abilities. Those who achieved strong knowledge results generally also felt more confident, and vice versa. In other words, by the end of the experiment, the components of STEM competence had become more coherent and interrelated.

These findings align with broader trends reported in the literature. Specifically, our experiment confirmed that the intentional integration of STEM elements into the educational process of pedagogical universities can significantly enhance future teachers' readiness for innovative practice. Students demonstrated growth in both the cognitive component (subject-methodological knowledge) and the motivational component, specifically the desire and confidence to implement new teaching approaches. This observation aligns with the conclusions of T. Molnar (2023), who found that incorporating STEM education into teacher preparation promotes a deeper understanding of complex material, strengthens responsibility, teamwork skills, and the ability to make informed professional decisions.

Our students experienced the benefits of integrated learning firsthand through project work, experiments, and interdisciplinary assignments, which had a positive impact on their attitudes. Notably, the greatest improvement was observed among bachelor's students who initially felt less prepared. This suggests that STEM modules are particularly effective at the foundational stage of teacher education, when students are still open to new methods and can be easily engaged in technology-driven, project-based learning, thus fostering a lasting interest in STEM.

The improvement among master's students was smaller, yet they started with a stronger base. Importantly, both groups ultimately achieved a relatively high level of STEM readiness (67–72% according to the index). This indicates that the implemented measures, including specialized workshops, project-based learning, practical training, and master classes, proved universally beneficial across different levels of teacher education.

The presence of a moderate correlation between the results of the two stages ($r \approx 0.46$) indicates that students who initially showed strong performance generally remained among the top achievers later on. At the same time, the relatively low strength of this correlation suggests that success at the final stage was not entirely determined by the starting level. In other words, the pedagogical intervention significantly reshaped the overall distribution of competencies among the participants. Some students who initially demonstrated gaps were able to compensate for them and reach a solid level of knowledge and confidence. This finding emphasizes the importance of providing targeted support for students with lower baseline readiness. The STEM-based approach can effectively enhance their performance if appropriate conditions are created, such as mentoring, supplementary consultations, and access to learning resources.

Conclusions

The conducted study confirmed the promising potential of integrating STEM education into the system of professional teacher preparation for primary schools. Theoretical analysis demonstrated that the STEM approach aligns with current educational development trends and the goals of the New

Ukrainian School reform. Integrated learning at the intersection of science and technology fosters the formation of competent, creative, and critically thinking teachers capable of educating a generation of students growing up in a highly technological environment. STEM competence should be considered an essential component of a modern teacher's professional competence, encompassing knowledge, practical skills, and innovative thinking.

International experience highlights the need for Ukraine to establish a regulatory and legal framework that prioritizes STEM as a strategic component of national educational policy and serves as the foundation for designing effective teacher education programs for primary schools. For Ukraine, the adaptation of Canadian practices appears particularly relevant, especially those related to post-graduate mentorship systems, partnerships between general and higher education institutions, and flexible formats of professional learning to ensure the sustainable development of STEM education.

The experimental part of our study demonstrated that even relatively short-term implementation of STEM elements (over one semester) can yield a measurable positive effect. Future teachers who participated in STEM projects, practical sessions, and workshops demonstrated significant improvements in both their knowledge and confidence in applying innovative teaching methods. They acquired specific practical skills and, more importantly, strengthened their motivation to experiment in their future professional practice. The average STEM readiness index increased from 59% to 69% ($p < 0.001$), with a correlation coefficient of $r = 0.46$ between the two stages.

It has been proven that the inclusion of STEM components in teacher education programs is both justified and effective, as it prepares future educators to assume the role of facilitators of inquiry-based learning and mentors capable of sparking children's interest in science and technology from the earliest years of schooling.

The prospects for further research lie in expanding the scale of experimental work. It would be worthwhile to conduct a comparative analysis of the outcomes of international STEM education projects implemented across various teacher training institutions. Another promising direction involves tracking how graduates who received STEM-oriented preparation apply innovative methods in real school practice and how these methods influence their students' learning achievements. Further investigation is also needed into specific aspects of STEM competence development, such as the formation of practical skills in using particular technologies (robotics, 3D modeling, and similar tools) in primary school teaching, as well as the psychological readiness of teachers to work in uncertain and exploratory learning environments.

Thus, STEM education opens broad opportunities for preparing teachers who can educate the modern generation using the methods of the future. Its integration into teacher education curricula represents an innovation that ensures continuity between the goals of school reform and the content of teacher training. The findings of our study demonstrate that STEM-oriented preparation contributes to the professional growth of future educators and fosters in them the confidence of innovators and researchers. This, in turn, will guarantee that schools are staffed with teachers who inspire children to explore, create, and think critically while effectively implementing the principles of STEM education in practice.

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