ANNOTATION

for the dissertation work towards the degree of Doctor of Philosophy (PhD) in the educational program «8D01501 – Physics»

BAKYTKAZY TANNUR

Formation of professional competence of school teachers on STEM education in teaching physics

General Characteristics of the Study. The dissertation is devoted to the issue of developing the professional competence of school teachers through the integration of STEM education elements into physics teaching. Within the framework of the study, the proposed approaches and content solutions are aimed at improving teachers' professional training in the STEM field and at developing their subject-specific, methodological, technological, and research competencies.

The study systematically examines ways to enhance the theoretical and practical training of physics teachers in STEM, and identifies the scientific and methodological foundations for their effective implementation in the educational process. In addition, the content and mechanisms for integrating STEM elements into teaching practice are specified, and provisions are proposed to improve pedagogical activity in this area.

The professional development course designed within the study is considered an important tool for teachers' professional growth, and its effectiveness is validated through experimental research. The obtained results make it possible to draw conclusions that serve as a basis for the formation and development of teachers' professional competence in the context of STEM education.

Relevance of the Research

Currently, the global labor market is undergoing profound transformations driven by digitalization, artificial intelligence, and technological change. The emergence of new professions and skill sets requires education systems not only to provide subject knowledge but also to develop interdisciplinary thinking, as well as research, engineering, and creative abilities. In this context, STEM education enhances students' understanding of interdisciplinary connections, fosters their research and creative skills aimed at solving real-world problems, and enables them to make informed decisions regarding their future career paths.

The effectiveness of career guidance systems in schools is a crucial factor in a country's economic and innovative development. At the 2025 Republican Teachers' Conference "The Future of Education: an Honest Citizen, a Professional Specialist," the President of the Republic of Kazakhstan, Kassym-Jomart Tokayev, emphasized the importance of early career guidance, noting that increasing interest in technical and vocational professions is one of the key prerequisites for sustainable national development.

Physics, as a fundamental science explaining the laws of natural phenomena, forms the scientific basis of engineering and technological education. Therefore, in teaching physics, particular importance is attached to integrating theoretical knowledge with practice, as well as to developing skills in scientific inquiry and solving technical problems. The effective implementation of these tasks directly depends on teachers'

readiness to systematically and purposefully apply STEM education elements in the learning process.

The growing demand for engineering and technical professions in the modern labor market, along with the results of international assessments of educational quality, highlights the need to improve the level of scientific literacy. This situation necessitates the enhancement of both the content and methodology of teaching natural sciences, including physics, in schools. At the same time, the implementation of STEM approaches in school practice reveals several challenges, particularly those related to insufficient theoretical preparation and practical experience of teachers.

In this regard, the scientific investigation of the problem of developing teachers' professional competence through the use of STEM elements in physics teaching is one of the pressing tasks of the modern education system.

Purpose of the Research: Substantiation of the scientific and methodological framework for developing the professional competence of school teachers for the effective implementation of STEM education elements in physics teaching.

Research Objectives

1. To analyze scientific literature and empirical studies related to the development of teachers' professional competence. To identify teachers' professional needs in applying STEM education in physics teaching through surveys and interviews, and to develop a model of professional competence.
2. To design the content, structure, and instructional-methodological support of the professional development course entitled "Integration of STEM Education Elements into Physics Teaching."
3. To experimentally verify the effectiveness of the proposed methodology and implement it in the educational process.

Research Methods

The research employed theoretical methods (analysis, systematization, and comparison of scientific literature), empirical methods (survey, interviews, observation, and pedagogical experiment), as well as statistical data processing and pedagogical interpretation of the results.

Object of the Research

The professional competence of teachers in integrating STEM education elements into physics teaching in secondary schools of the Republic of Kazakhstan.

Subject of the Research

The theoretical foundations, methodology, and pedagogical conditions for developing the professional competence of school teachers in integrating STEM education elements into physics teaching.

Scientific Novelty of the Research

For the first time:

1. In the context of Kazakhstan, through a comprehensive empirical study, the professional needs of physics teachers in mastering STEM education elements and the difficulties of implementing them in educational practice were identified. A structural model of physics teachers' professional competence in the STEM context was developed, including interconnected components: scientific-subject, methodological, technological, and reflective competencies.

2. Taking into account the characteristics of the education system in Kazakhstan, the content and structure of a modular professional development course aimed at developing physics teachers' professional competence in STEM were scientifically substantiated and developed.

3. The influence of the developed course on the formation of teachers' professional competence in STEM education and on students' learning outcomes was experimentally confirmed.

Provisions Submitted for Defense:

1. The proposed model, consisting of seven cyclical components, designed to form the professional competence of teachers in the context of STEM education, through its cyclical-stage structure, serves as the basis for identifying insufficient components of the teacher's professional competence.

2. The advantages of the program "Integrating STEM elements into physics teaching" are the availability of 3 months of remote mentoring support and the methodology for developing STEM box. The program was evaluated in accordance with international standards and showed a score of 4.64/5.00.

3. Teachers who completed the professional development course "Integration of STEM Elements into Physics Teaching" showed positive dynamics across all components of professional competence: subject-matter competence increased from 2.32 to 4.28, methodological competence from 2.12 to 4.16, technological competence from 1.96 to 4.08, engineering competence from 1.88 to 4.00, interdisciplinary competence from 2.24 to 4.20, research competence from 2.28 to 4.24, and reflective competence from 2.44 to 4.36. The overall level of professional competence in STEM increased from 2.18 to 4.22 ($p < 0.001$), with an average gain of +2.04 points.

Scientific and Practical Significance of the Study

The practical significance of the study lies in the following: the developed professional development course "Integration of STEM Elements into Physics Teaching" has been implemented in professional development programs for physics teachers within the education system of the Republic of Kazakhstan.

The learning materials, methodological guidelines, practical tasks, and assessment tools developed within the course serve as accessible resources for teachers' professional development.

The research results can be used in educational programs of pedagogical universities, in professional development centers, and in school-based methodological seminars. The developed STEM lesson plans, practical activities, and project tasks can be directly applied in teachers' daily teaching practice.

The professional needs and difficulties of teachers identified during the study can serve as a basis for improving educational policy and developing teacher support programs.

Author's Contribution

All stages of the research—from the development of the theoretical concept to the practical implementation and processing of scientific results—were carried out with the direct participation of the author.

Approbation of the dissertation. The results obtained in the dissertation have been published, presented, and discussed in scientific publications and at international conferences.

Articles with impact factor included in the international scientific databases Scopus and Web of Science:

1. **Bakytkazy T**., Balta N., Tzafilkou K., Zhumabay N., Nurgaliyeva K., & Nadelson L. S. (2025). Unveiling the landscape of STEM education research in teaching: Teachers' perceptions and practices. European Journal of STEM Education. – 2025. – Т. 9. – № 1. Scopus (Q1). SJR: 0.557, H-Index: 9. ISSN: 2468-4368. Publisher: Lectito (Netherlands). Open Access. процентиль 76%. https://doi.org/10.20897/ejsteme/17355
2. Yelemessova Z., Balta N.; Abylkassymova A., Richelle M.; Zhumabay N., **Bakytkazy T**. Designing effective STEM courses: a mixed-methods study of the impact of a STEM education course on teachers' self-efficacy and course experiences Frontiers in Education. – Frontiers Media SA. – 2024. – Т. 9. – С. 1276828. DOI: https://doi.org/10.3389/feduc.2024.1276828. Scopus, процентиль 71%.
3. **Bakytkazy T**., Nurgaliyeva K., Japashov N., Zhumabay N. Examining the Pedagogical Abilities and Needs of Kazak Physics Teachers to Implement STEM Education// Part of the book series: Lecture Notes in Networks and Systems (LNNS,volume 1261). ICL2024 – 27th International Conference on Interactive Collaborative Learning, 24–27 September 2024, TalTech, Tallinn, Estonia, p. 1033-1044, Scopus (Q4), SiteScore-0,9; SJR-0.171, процентиль -22%, indexed by WoS https://doi.org/10.1007/978-3-031-85649-5_25
4. **Bakytkazy T**., Nurgaliyeva K., Japashov N., Zhumabay N. Purpose And Characteristics Of STEM Education In Both The United States And Kazakhstan// Part of the book series: Lecture Notes in Networks and Systems (LNNS,volume 1261). ICL2024 – 27th International Conference on Interactive Collaborative Learning, 24–27 September 2024, TalTech, Tallinn, Estonia, p. 1539-1546, p. 1033-1044, Scopus (Q4), SiteScore-0,9; SJR-0.171, процентиль -22%, indexed by WoS. https://doi.org/10.1007/978-3-031-85649-5_26

Presentations at international scientific conferences:

1. Nurgaliyeva K., **Bakytkazy T.**, Ferreira E., Nicola S. Approaches to course development for teaching physics via STEM education in schools. 54th IGIP International Conference on Interactive Collaborative Learning, – 01-03 October 2025, – Budapest, Hungary.
2. **Bakytkazy T**., & Alisheva, A. N. Problems of methodology for explaining basic physical concepts in natural science lessons in primary school. In: International Scientific and Practical Conference "Farabi Alemi", Almaty, Kazakhstan, 6–7 April 2023, p. 342.
3. **Bakytkazy T**., & Nurgaliyeva, K. E. Purpose and characteristics of STEM education in the United States of America. In: Modern Trends in Physics: Integration of Science and Education, Proceedings of the International Scientific

Conference (February 23, 2024, Astana, Kazakhstan). Astana: L. N. Gumilyov Eurasian National University Publishing House, 2024.

4. **Bakytkazy T**., & Nurgaliyeva, K. E. Purpose and characteristics of STEM education in the USA and Kazakhstan. In: Development of Natural Science Education in the Republic of Kazakhstan: Problems and Prospects, Proceedings of the International Scientific and Practical Conference. Almaty: Center of оперативной полиграфии Publishing House, 2024.

Copyright Certificates

– **Bakytkazy T**., & Nurgaliyeva, K. E. Course program "Integration of STEM Education Elements in Physics Teaching." Copyright Certificate No. 65266, December 11, 2025. Literary work. Date of creation: December 10, 2025.

– **Bakytkazy T**. Elective course "Teaching Physics through STEM Education" for 10th grade students. Copyright certificate, Protocol No. 1, February 4, 2025.

Correlation of the dissertation topic with research work plans.

Structure and Scope of the Dissertation

The dissertation was carried out within the framework of fundamental research under the grant funding program of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, under the project "AP26101969 Development and implementation of a synergistic model for training an innovation-active educator and fostering their professional development in the context of globalization, digitalization, and inclusive education."

The dissertation consists of an introduction, three main chapters, a conclusion, a list of references, and appendices. The work comprises 164 pages and includes 30 tables, 7 formulas, 26 figures, and 178 references.