Journal of Teaching, Learning & Curriculum (JTLC)
Volume 2 Issue 1 Year 2026 Pages 31- 36
E-ISSN : 3110-3707 | DOI: 10.61227
E-mail : jtlc.journal@gmail.com
https://journal.pusmedia.com/index.php/JTLC/index

Integrative Scientific-Methodological Preparation of Pre-Service Physics Teachers: A Competency-Based Model for Professional Development

Iroda Baxtiyor qizi Doniyorova[1]*

[1] Faculty of Pedagogy, Department of Primary Education, Karshi State University, Uzbekistan.

Correspondence e-mail * : nilufarpardaevna1@gmail.com

Abstract : The transformation of global education systems necessitates a new generation of physics teachers capable of integrating scientific expertise with advanced pedagogical methodology. Despite substantial reforms in teacher education, a persistent fragmentation between disciplinary knowledge and instructional methodology limits the development of holistic professional competence. This study proposes and empirically validates an integrative competency-based model for the scientific-methodological preparation of pre-service physics teachers. The model is theoretically grounded in Shulman's Pedagogical Content Knowledge (PCK), Mishra and Koehler's Technological Pedagogical Content Knowledge (TPACK), the OECD Education 2030 framework, and UNESCO's Teacher Competency Framework. Scientific-methodological competence is conceptualized through four interrelated components: cognitive, operational, reflexive, and innovative. A mixed-method research design was implemented with 124 pre-service physics teachers. Diagnostic surveys, pedagogical performance assessments, reflective inventories, and expert evaluations were used to measure competency growth. Quantitative analysis using paired-sample t-tests revealed statistically significant improvements across all components following structured model implementation ($p < .01$). The findings demonstrate that systematic integration of scientific reasoning, methodological design, STEAM-oriented instruction, and reflective pedagogical practice substantially enhances professional readiness. The study contributes a structured diagnostic toolkit and a scalable professional development framework adaptable to contemporary competency-based teacher education systems. The proposed model represents a novel integration of scientific epistemology, pedagogical modeling, and innovation-oriented competence development in physics education.

Keyword : scientific-methodological competence, physics teacher education, competency-based model, PCK, TPACK, STEAM integration, pedagogical diagnostics

Article info: Submitted : 2026-02-20 | Accepted : 2026-04-15 | Published : 2026-04-23

INTRODUCTION

The accelerating transformation of educational systems worldwide has intensified the demand for teachers who possess not only disciplinary knowledge but also integrative methodological competence. In physics education, this challenge is particularly acute due to the abstract, mathematically grounded, and experimentally driven nature of the discipline. Contemporary educational reforms emphasize competency-based frameworks that align teacher preparation with adaptive expertise, technological integration, and innovation (OECD, 2018).

Despite theoretical advancements, the preparation of pre-service physics teachers frequently remains compartmentalized. Disciplinary courses prioritize theoretical physics knowledge, while pedagogical training addresses general instructional strategies. The absence of systematic integration weakens the development of scientific-methodological competence—understood as the ability to transform scientific knowledge into pedagogically meaningful instruction.

Shulman's (1986) concept of Pedagogical Content Knowledge (PCK) laid the foundation for integrating content and pedagogy. Subsequent developments, including the TPACK framework (Mishra & Koehler, 2006), incorporated technological knowledge. However, in physics education, the operationalization of integrative competence remains insufficiently structured, particularly regarding diagnostic measurement and model validation.

The purpose of this study is to design and empirically validate a competency-based model for the scientific-methodological preparation of pre-service physics teachers. The study addresses three research questions:

1. How can scientific-methodological competence in physics teacher education be conceptually structured?
2. What integrative model ensures systematic development of cognitive, operational, reflexive, and innovative components?
3. Does structured implementation of the model significantly improve professional readiness?

Literature Review

1. Pedagogical Content Knowledge in Physics Education

Shulman (1986) introduced PCK as a synthesis of subject knowledge and pedagogical understanding. In physics, PCK involves conceptual modeling, representation of invisible phenomena, use of experiments, and scaffolding of abstract reasoning. Research in physics education (Meltzer & Thornton, 2012; Docktor & Mestre, 2014) demonstrates that effective teaching depends on teachers' capacity to translate disciplinary epistemology into learning trajectories.

2. Technological Integration: TPACK and Digital Competence

Mishra and Koehler (2006) expanded PCK into the TPACK model by integrating technological knowledge. In physics, digital simulations, computational modeling, and virtual laboratories are essential tools for conceptual understanding. Koehler et al. (2014) and Voogt et al. (2015) argue that technology enhances instructional effectiveness when aligned with epistemological structures of the discipline.

3. Competency-Based Teacher Education

Darling-Hammond (2017) emphasizes coherent teacher preparation systems integrating theory, practice, and reflection. The OECD Education 2030 Learning Compass highlights transformative competencies such as innovation and responsibility. UNESCO (2018) stresses ICT integration and reflective practice in teacher competence frameworks.
These theoretical perspectives justify structuring scientific-methodological preparation through measurable components aligned with competency-based education.

METHODOLOGY

Research Design

A mixed-method quasi-experimental design was employed. Participants included 124 pre-service physics teachers enrolled in a teacher education program. The study was conducted over one academic semester (16 weeks).

Model Development

The integrative model was developed through pedagogical modeling techniques, including:

1. Structural component analysis
2. Competency mapping
3. Expert validation (n=8 specialists)

Diagnostic Instruments

Four instruments were developed and validated:

1. Scientific-Methodological Competence Questionnaire (SMCQ)
2. Classroom Simulation Performance Rubric
3. Reflective Practice Inventory
4. Innovation-Oriented Teaching Checklist

Competence Structure

Table 1. Scientific-Methodological Competence Was Operationalized Through Four Components

Component	Description	Indicators
Cognitive	Mastery of physics concepts and epistemology	Conceptual modeling, theoretical integration
Operational	Instructional design and classroom implementation	Lesson planning, experiment design
Reflexive	Reflective pedagogical awareness	Self-analysis, feedback adaptation
Innovative	STEAM and technological creativity	Digital tools, interdisciplinary tasks

RESULTS AND DISCUSSION

Result

1. Pre- and Post-Diagnostic Analysis

Quantitative analysis revealed statistically significant growth across all components.

Table 2. Descriptive Statistics of Competency Components

Component	Pre-test Mean	Post-test Mean	Std. Dev (Pre)	Std. Dev (Post)	t-value	p-value
Cognitive	3.12	4.26	0.54	0.48	11.24	<.001
Operational	2.94	4.08	0.61	0.52	10.87	<.001
Reflexive	3.01	4.34	0.58	0.46	12.13	<.001
Innovative	2.76	4.19	0.65	0.49	13.02	<.001

All improvements were statistically significant at $p < .01$.

2. Competency Level Distribution

Table 2. Distribution of Competency Levels (%)

Level	Pre-test (%)	Post-test (%)
Low	38%	7%
Medium	46%	29%
High	16%	64%

The proportion of participants demonstrating high-level competence increased from 16% to 64%.

3. Correlation Analysis

Table 3. Pearson Correlation Matrix (Post-test)

Component	Cognitive	Operational	Reflexive	Innovative
Cognitive	1.00	0.71	0.65	0.68
Operational	0.71	1.00	0.73	0.75
Reflexive	0.65	0.73	1.00	0.78
Innovative	0.68	0.75	0.78	1.00

Strong positive correlations indicate systemic integration among components.

Discussion

The results confirm that integrative preparation significantly enhances professional competence. Growth across components demonstrates that scientific knowledge alone is insufficient without methodological transformation and reflective adaptation.

The strong correlations among components indicate systemic integration rather than isolated development. The innovative component showed the highest growth rate, suggesting that STEAM-oriented design and digital pedagogy play a transformative role.

Compared with traditional linear models of teacher preparation, the proposed framework promotes adaptive expertise, consistent with OECD (2018) transformative competencies.

The study advances PCK and TPACK frameworks by embedding them within a structured competency diagnostic model specific to physics education.

CONCLUSION

This study developed and empirically validated an integrative competency-based model for the scientific-methodological preparation of pre-service physics teachers. The model operationalizes professional readiness through cognitive, operational, reflexive, and innovative components.

Statistical analysis confirms significant competence growth following structured implementation. The model provides:

1. A diagnostic toolkit
2. A scalable curriculum framework
3. A STEAM-integrated pedagogical structure

The scientific novelty lies in the systemic integration of disciplinary epistemology, pedagogical modeling, and innovation-oriented competence measurement within physics teacher education.

Future research should examine longitudinal application and cross-cultural validation.

REFERENCES

Abduqodirov, A. A. (2016). *Fizika o'qitish metodikasi asoslari*. Tashkent: O'qituvchi.

Azizov, A. A. (2019). Innovative approaches in modern physics education. *Fizika, matematika va informatika, 4*(1), 25–33.

Darling-Hammond, L. (2017). Teacher education around the world: What can we learn from international practice? *European Journal of Teacher Education, 40*(3), 291–309. https://doi.org/10.1080/02619768.2017.1315399

Docktor, J. L., & Mestre, J. P. (2014). Synthesis of discipline-based education research in physics. *Physical Review Special Topics–Physics Education Research, 10*(2), 020119. https://doi.org/10.1103/PhysRevSTPER.10.020119

Ergashev, N. N. (2020). STEAM-based methodology in physics instruction. *Zamonaviy ta'lim, 5*(2), 52–60.

Ismoilov, K. M. (2015). *Umumiy fizika kursi va o'qitish metodikasi*. Tashkent: Fan.

Karimov, B. B. (2018). Implementation of competency-based approaches in physics teaching. *Pedagogik mahorat, 1*(4), 78–84.

Khimmataliev, D. X. (2018). *Pedagogik texnologiyalar va kasbiy kompetensiyalarni rivojlantirish metodologiyasi*. Tashkent: Fan va texnologiya.

Khimmataliev, D. X. (2020). Competency-based approach in professional teacher training: Methodological foundations. *Pedagogika va psixologiya, 3*(2), 15–27.

Koehler, M. J., Mishra, P., & Cain, W. (2014). What is technological pedagogical content knowledge (TPACK)? *Journal of Education, 193*(3), 13–19.

Mamatov, R. M. (2021). Digital modernization of physics education. *Innovatsion ta'lim, 3*(6), 33–44.

Meltzer, D. E., & Thornton, R. K. (2012). Active-learning instruction in physics. *American Journal of Physics, 80*(6), 478–496. https://doi.org/10.1119/1.3678299

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054.

National Research Council. (2012). *A framework for K–12 science education*. National Academies Press.

Nishonov, Y. T. (2014). *Fizika o'qitish metodikasi*. Tashkent: Universitet.

OECD. (2018). *The future of education and skills: Education 2030*. OECD Publishing.

OECD. (2019). *PISA 2018 results: What students know and can do*. OECD Publishing.

Omonova, N. P. (2021). Development of information competence of future teachers in digital educational environments. *Scientific Bulletin of CSPU, 2*(5), 67–79.

Omonova, N. P. (2023). AI-based adaptive learning models in teacher education. *Innovative Education Review, 6*(1), 88–102.

Rahimov, Sh. Sh. (2019). Experimental activity in physics lessons. *Fizika va texnologiya, 2*(2), 15–23.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Tursunov, H. R. (2022). Mechanisms of professional competence formation in physics teachers. *Ilmiy tadqiqotlar jurnali, 7*(1), 92–104.

UNESCO. (2018). *ICT competency framework for teachers (Version 3)*. UNESCO Publishing.

UNESCO. (2021). *Reimagining our futures together: A new social* *contract for education*. UNESCO Publishing.

Voogt, J., Fisser, P., Pareja Roblin, N., Tondeur, J., & Van Braak, J. (2015). Technological pedagogical content knowledge: A review. *Journal of Computer Assisted Learning, 31*(2), 98–110.

Wieman, C. (2017). *Improving how universities teach science*. Harvard University Press.

AUTHOR CONTRIBUTIONS

Conceptualization: All Authors ;

Methodology: All Authors ;

Investigation: All Authors ;

Writing—original draft preparation: All Authors ;

Writing—review and editing: All Authors ;

Visualization: All Authors ;

All authors have read and agreed to the published version of the manuscript.