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THE FORMATION OF STUDENTS' SUBJECT COMPETENCE IN PHYSICS IN THE CONDITIONS OF STEM EDUCATION IN UKRAINE AND USA

The current stage of higher education development is characterized by the active implementation of a STEM-oriented approach, which is due to the needs of a high-tech society and the need to train specialists capable of interdisciplinary activities, critical thinking and solving complex applied problems. In this context, the formation of students' subject competence in physics as a basic component of STEM education is of particular importance.

Physics as a fundamental science provides a theoretical basis for the development of technologies, engineering and innovations, which determines its key role in the structure of STEM competencies. At the same time, modern requirements for the training of specialists involve not only the acquisition of theoretical knowledge, but also the development of research, analytical, computational and communicative skills that ensure the ability to perform effective professional activities.

An analysis of the practice of functioning of higher education institutions shows that the process of forming subject competence in physics in Ukraine is at the stage of modernization. Despite the presence of strong fundamental training, there is insufficient integration of STEM approaches, limited use of modern digital technologies, as well as uneven implementation of research and project-based teaching methods.

In comparison, the USA has formed a more flexible and practice-oriented STEM education system, which is based on clearly defined learning outcomes, active involvement of students in research activities, and integration of the educational process with the requirements of the labor market. This necessitates the understanding and adaptation of best foreign practices in the domestic educational system.

Thus, the relevance of the study is determined by the need for a deep analysis of the features of the formation of subject competence of students in physics in the conditions of STEM education, the identification of common and distinctive features of the educational models of Ukraine and the

USA, as well as substantiation of directions for improving the national higher education system in accordance with modern challenges and international trends.

This is of particular importance for Ukraine in the context of post-war reconstruction, which requires the development of critical thinking, practical skills, and a close combination of theoretical knowledge with real challenges. Given the rich experience of the United States in the field of innovation, such studies open up the opportunity to understand how the integration of physics with other disciplines contributes to the formation of creativity and competitiveness, which can become a valuable basis for improving the Ukrainian education system. Ukraine needs specialists who are able to create innovative solutions in the fields of engineering, programming, and science. The development of a developed STEM education system is a determining factor for the formation of highly qualified personnel. An analysis of how physics in the United States is combined with engineering, technology, and mathematics in curricula compared to Ukrainian realities contributes to the formation of creativity and interdisciplinary vision, helping students adapt to the requirements of the modern world and the rapid development of innovative technologies. Given the current trends in teaching physics and the peculiarities of the educational process, the importance of developing competencies becomes a key aspect in the formation of a personality, proposes a concept of integrating theoretical knowledge with practical STEM tasks to stimulate the active intellectual and personal development of students. In this context, the study of physics goes beyond the simple mastery of basic concepts, focusing on the ability to apply them in real practical tasks. Therefore, such research can become an important tool for the strategic improvement of the Ukrainian higher education system, aimed at meeting modern global standards and strengthening the country's innovative potential.

In modern scientific and pedagogical research, the formation of subject competence in physics in higher education institutions is considered as a component of a broader process of developing STEM competencies, which includes the integration of knowledge, skills and abilities in an interdisciplinary context (Batyuk, 2025c). Researchers emphasize that STEM education is not just a combination of disciplines, but a learning paradigm focused on interdisciplinarity, practical application of knowledge, solving real problems, developing critical thinking and an engineering approach (Barna, Kuzminska & Semerikov, 2025; Batyuk & Masych, 2025a). In this context, physics acts as a basic discipline that provides the foundation for the formation of a scientific worldview and research skills.

In Ukraine, STEM education is at the stage of active development and modernization. The main trends are the introduction of the STEM concept (from 2020), updating educational standards, integrating STEM courses into curricula, and using digital technologies. Modern Ukrainian research focuses on the need to update the content of education, integrate innovative technologies, and form innovative and research competence. In particular, it has been established that the formation of competence effectively occurs under the conditions of modeling, experimental activities, the use of STEM projects, and the introduction of digital tools (Bondarenko & Kryvylova, 2024). Some studies prove that the digital integration of physics contributes to the development of professional competencies, digital literacy, and engineering thinking of future specialists (Batyuk, 2026b). At the same time, researchers note such problems as insufficient material and technical base, fragmented implementation of STEM, insufficient level of teacher training, and limited integration between disciplines.

American studies demonstrate the systemic nature of STEM education, which is manifested in state support and financing, the presence of a clear regulatory framework, integrated educational programs, and orientation to the needs of the labor market (Batyuk, 2025b). The key approaches to implementing STEM education in the USA are problem-based learning, project-based learning, engineering design approach, active use of laboratories and digital technologies. This ensures the formation of applied knowledge in physics, research skills, and the ability to innovate in students. Comparative studies show both common features and significant differences (Boichenko & Boichenko, 2019). Among the common features, the following should be highlighted:

– STEM is a priority of the educational policy of both countries;
– Orientation on the formation of competence, not just knowledge;
– Integration of science, technology, engineering, and mathematics;
– Development of students' research activities.

Among the differences, it is necessary to highlight:
– Level of implementation (in Ukraine – separate stages of development, in the USA – systemic, institutionalized);
– Methodology (in Ukraine – partially integrated, in the USA – project, engineering, interdisciplinary);
– Technological base (in Ukraine – high level, in the USA – limited);
– Teacher training (in Ukraine – needs improvement, in the USA – systemic);
– Integration of physics (in Ukraine – partial; in the USA – full STEM-integration).

Analysis of modern scientific works allows us to identify key research trends:
1) transition from subject-based to competency-based teaching of physics;
2) strengthening the role of digital technologies;
3) integration of physics with engineering and IT;
4) development of STEM laboratories and educational ecosystems;
5) orientation towards the formation of 21st century skills.

Promising research areas include the development of models for the formation of subject competence in the STEM environment; adaptation of American experience to Ukrainian conditions; creation of methods for integrated teaching of physics; development of digital STEM platforms. The analysis of research shows that the formation of subject competence of students in physics in the context of STEM education is a strategically important direction for the development of education in both Ukraine and the USA. The American model is characterized by systematicity, integration and a high level of practical orientation, while the Ukrainian system is at the stage of transformation, gradually adopting effective STEM practices. The comparative analysis confirms the feasibility of adapting innovative approaches from the USA, strengthening interdisciplinarity, and developing digital infrastructure, which in general will contribute to improving the quality of education and the formation of competitive specialists.

The purpose of the article is to conduct a comparative analysis of the features of the formation of students' subject competence in physics in the conditions of STEM education in higher education institutions of Ukraine and the USA based on the study of their theoretical principles, structural components, implementation models and regulatory support in order to identify common trends and differences.

The methodological basis of the study is the provisions of the competency-based, systemic and interdisciplinary approaches, which provide a holistic understanding of the process of forming subject competence of students in physics in the context of STEM education.

The materials of the study were scientific works of domestic and foreign researchers devoted to the problems of STEM education and the formation of subject competence; regulatory and legal documents of Ukraine in the field of education, regulating the competency-based approach and the implementation of STEM education; international framework documents and analytical materials, which determine the current trends in the development of STEM competence; methodological recommendations and standards for the training of physics specialists in higher education institutions in Ukraine and the USA.

To achieve the goal of the study, a set of interrelated methods was used theoretical methods (analysis, synthesis, generalization, systematization) – to process scientific sources, determine the essence of the concept of «subject competence in physics», identify its structural components and substantiate the role of STEM education; comparative-pedagogical (comparative) analysis – to compare approaches to the formation of STEM competence in physics in Ukraine and the USA, identify common features and differences in educational models; structural-functional analysis – to build a model of the formation of STEM competence in physics and determine its main components (target, content, methodological, technological, activity, evaluation and effective); analysis of regulatory documents – to study the features of the regulation of STEM education and the competency approach at the national and international levels; method of generalizing pedagogical experience – to identify effective practices for the formation of STEM competence in higher education institutions.

The use of these methods allowed for a holistic analysis of the research problem, to substantiate the features of the formation of subject competence of physics students in the conditions of STEM education, and to identify areas for its improvement, taking into account international experience.

STEM education in Ukraine is currently being actively formed as a priority of the reform of science and mathematics education, including in higher education (On approval of the Strategy for the Development of Higher Education in Ukraine for 2022–2032, 2026). It is defined by the Concept for the Development of STEM Education in Ukraine (until 2027) and is focused on increasing the role of disciplines such as physics in the formation of competence of future specialists (On approval of the action plan for the implementation of the Concept for the Development of Science and Mathematics Education (STEM Education) until 2027, 2021). STEM approaches are more integrated into individual disciplines and project modules than as a single national educational framework with clear standard competences.

In the USA, STEM education has a long history of regulatory support: federal programs, autonomous accreditation of universities, funding for scientific research, practical alignment of educational programs with labor requirements (Batyuk, 2026a). Many universities have their own standardized learning outcomes (expected results) for physics programs that define knowledge, skills, and competence. For example, the «Phys21 report» describes a set of competences in modern physics as «analytical skills, computational tools, teamwork, communication, etc.» (Phys21: Preparing Physics Students for 21st Century Careers, 2016).

The formation of students' subject competence in physics is a one of key task of modern higher education, especially in the context of the development of STEM education as an integrative educational approach. Subject competence in physics is considered as an integral characteristic that includes a system of knowledge, skills, abilities, experience of activity, and value orientations necessary for understanding physical phenomena and applying the laws of physics in professional activities. Table 1 lists the framework documents that regulate the formation of students' subject competence in physics in STEM education in Ukraine and the USA.

A comparative analysis of the framework documents regulating the formation of students' subject competence in physics in STEM education in Ukraine and the USA indicates the presence of both common strategic guidelines and significant differences in approaches to organizing the educational process (see Table 1).

First of all, the higher education systems of both countries differ in the type of management. In Ukraine, it is predominantly centralized, which is manifested in the significant role of the state in determining educational standards, teaching content, and requirements for results. In contrast, in the USA, the system is decentralized, where the autonomy of universities, as well as professional organizations and accreditation institutions, play a key role.

Regulatory and legal support in Ukraine is based on basic legislative acts in the field of education and national standards that regulate the competency-based approach and determine program learning outcomes. An important element is the national qualifications framework, which is coordinated with European educational structures. In the USA, there is no single national regulatory document that would regulate STEM education, but there are numerous strategic initiatives, as well as recommendations from professional associations that determine the content and quality of training.

Table 1

Comparative analysis of framework documents of the formation of students' subject competence in physics in STEM education in Ukraine and USA

Criterion	Ukraine	USA
Type of education system	Centralized, regulated by the state	Decentralized, autonomy of universities
Basic laws in the field of education	Law of Ukraine «On Education» (Law of Ukraine «On Education», 2026), Law of Ukraine «On Higher Education» (Law of Ukraine «On Higher Education», 2026)	Lack of a single federal law; regulation at the state and institutional levels (Batyuk, 2026a)
National Qualifications Frameworks	The National Qualifications Framework (NQF) is aligned with the EQF (National Qualifications Framework, 2020; National Qualifications Framework, 2026; Zakharchenko et al., 2017; Law of Ukraine «On Amendments to Certain Laws of Ukraine on Improving Educational Activities in the Sphere of Higher Education», 2020; On approval of the National Qualifications Framework, 2026; The European Qualifications Framework. European Union, 2026; On the establishment of the National Coordination Center of the European Qualifications Framework for Lifelong Learning in Ukraine, 2023)	Lack of a single NQF; use of institutional frameworks (Batyuk & Zhernovnykova, 2025; Otero, 2015)
STEM strategy	Concept of STEM education development until 2027 (On approval of the action plan for the implementation of the Concept for the Development of Science and Mathematics Education (STEM Education) until 2027, 2021)	National Science Foundation – STEM Education Strategic Plan (A STEM Education Strategic Plan, 2025); Federal STEM initiatives (Batyuk, 2026a)
International integration	Bologna Process (Bugrov et al., 2014; Khaidari, Zasluzhena & Yukhnovets, 2024), EQF (The European Qualifications Framework. European Union, 2026), QF-EHEA (The framework of qualifications for the European Higher Education Area, 2018)	Partial integration; orientation towards global rankings and research standards
Educational standards (physics)	Developed at the level of higher education institutions and the Ministry of Education and Science of Ukraine (Approved standards of higher education, 2026; On approval of Methodological recommendations for the development of higher education standards, 2025; Methodological recommendations for the development of higher education standards, 2017)	American Physical Society (Phys21, 2016), American Association of Physics Teachers (AIP, 2026; Physics in 21st Century Science Standards: The Role of Physics in the NGSS*, 2017; Physics in 21st Century Science Standards: The Role of Physics in the NGSS*, 2026; Calmer, 2019; The State of State Science Standards, 2012)
Accreditation of educational programs	National Agency for Quality Assurance in Higher Education (On approval of the Regulations on accreditation of educational programs for training higher education applicants, 2024; Stukalo, Trebenko, Knysh & Shylina, 2025)	ABET (Accredited Programs, 2026)
Approach to determining competence	Determined by state education standards (Rashkevych, 2016; On approval of Methodological recommendations for the development of standards of vocational (vocational and technical) education using a competency-based approach, 2021)	Determined through learning outcomes at the program level (Fischer & Kauertz, 2021; Rajapaksha & Hirsch, 2017)
Orientation of STEM competence	Mostly theoretical, with gradual practical integration	Practically oriented, integrated with industry
Role of research	Limited by resources, gradually integrated	Key element of education (research-based learning)
Digital and computational competence	Developing, but unevenly (Batyuk & Zhernovnykova, 2018)	Is a mandatory component of STEM training
Global landmarks	Organization for Economic Co-operation and Development, UNESCO	Organization for Economic Co-operation and Development (OECD future of education and skills 2030, 2019; OECD, 2023), UNESCO (UNESCO, 2025)

A significant difference is the approach to standardizing STEM competence. In Ukraine, it is implemented through state education standards, which establish general requirements for the training of applicants. In the USA, the main emphasis is on formulating learning outcomes at the level of educational programs, which provides greater flexibility and adaptability to the needs of the labor market (Setting the National Standard for Undergraduate Physics Education, 2026; Batyuk, 2026b).

An analysis of STEM strategies shows that in Ukraine they have a holistic state character and are aimed at the gradual integration of STEM approaches into the education system. In the USA, the development of STEM education is supported by national initiatives implemented through cooperation between government agencies, universities, and the private sector (Batyuk, 2025a; Physics and 21st Century Science Standards: The Role of Physics in the NGSS*, 2017).

An important aspect is the role of professional organizations and standards in the field of physics. In Ukraine, they are at the stage of formation and are mainly implemented through educational programs of individual institutions. In the USA, professional associations play a leading role in defining competence, curriculum structure, and requirements for training physicists (Batyuk & Masych, 2025b).

Accreditation of educational programs also differs: in Ukraine it is carried out by national bodies, while in the USA it is carried out by independent accreditation agencies that set high quality standards for STEM education (Science Education in the United States: Standards and Challenges, 2026; Batyuk, 2025b).

Regarding the content of competence formation, in Ukraine there is a predominantly theoretical orientation with the gradual introduction of practical elements. In the USA, on the contrary, a practice-oriented approach dominates, which involves the active involvement of students in research activities, the use of modern technologies and the development of applied skills (American Physical Society, 2026; Hestenes, Megowan-Romanowicz, Popp, Jackson & Culbertson, 2011).

Computational and digital competence are recognized as important in both systems, but the level of their integration differs significantly: in the USA they are an integral part of the educational process, while in Ukraine their implementation still requires systemic development. At the same time, both countries are guided by international educational standards and recommendations of leading organizations, which contributes to the unification of approaches to the formation of STEM competence in the global educational space (Soroko & Shymon, 2025; Batyuk, 2025a; Cosgrove & Cachia, 2025; Digital Competence Framework for Citizens of Ukraine, 2023; Sala, Punie, Garkov & Cabrera, 2020; DeCoito, Fazio & Gichuru, 2024; Vuorikari, Kluzer & Punie, 2022). Thus, the results of the comparative analysis allow us to state that the effectiveness of the formation of STEM competence in physics largely depends on the consistency of the regulatory framework, the level of autonomy of educational institutions, the degree of integration with the scientific environment and the orientation towards practical learning outcomes. The use of best practices from the USA can become an important factor in the modernization of the Ukrainian higher education system.

In the context of STEM education, physics is a fundamental discipline that provides a scientific basis for engineering, technology and mathematical modeling. Accordingly, the formation of subject competence involves not only the acquisition of theoretical knowledge, but also the development of the ability to interdisciplinary thinking, research activities and the use of digital technologies.

In Ukraine, the process of forming subject competence in physics is carried out in the context of the modernization of the educational system and the implementation of a STEM-oriented approach. The main regulatory guideline is the Concept of the Development of STEM Education in Ukraine until 2027, which defines the integration of natural and mathematical disciplines, the development of critical thinking and practical skills.

The characteristic features of the Ukrainian model are:

– Dominance of fundamental training: significant attention is paid to the classical sections of physics (mechanics, electrodynamics, quantum physics), which provides a deep theoretical foundation.

– Gradual integration of STEM approaches: the use of interdisciplinary tasks, project learning and STEAM elements.

– Limited material and technical base: complicates the implementation of experimental and research components.

– Uneven implementation of innovations: depends on the resources of a particular higher education institution.

Despite the above difficulties, the Ukrainian system demonstrates the potential for development through the integration of digital technologies, participation in international educational programs and adaptation of European standards.

In the USA, the formation of students' subject competence in physics is carried out in the conditions of a developed STEM ecosystem that combines education, science and industry. Educational programs are focused on achieving clearly defined learning outcomes that cover both subject knowledge and professional competence.

Key characteristics:

– Practice-oriented approach: significant attention is paid to laboratory research, experiments and real cases.

– Integration of computational methods: programming, modeling and data analysis are an integral part of physics education.

– Developed research activities: students are actively involved in scientific projects, grants, internships.

– Formation of soft skills: communication, teamwork, scientific writing and presentation of results.

The American model is focused on training specialists capable of working in a high-tech economy, which ensures high competitiveness of graduates. Table 2 presents a model for the formation of students' subject competence in physics in STEM education in Ukraine and the USA.

Table 2

The conceptual model for the formation of students' subject competence in physics in STEM education in higher education institutions in Ukraine and USA

Model Component	Ukraine	USA
Target component	Formation of fundamental knowledge in physics, development of scientific thinking, gradual integration of STEM	Formation of comprehensive STEM competence, orientation towards practical application and the labor market
Regulatory framework	Concept of STEM education development, Law «On Higher Education», national standards	Federal STEM initiatives, accreditation standards (ABET), recommendations of professional associations
Content component	Classical sections of physics (mechanics, electrodynamics, quantum physics) with elements of interdisciplinarity	Integrated STEM content: physics + programming + engineering + data analysis
Methodological component	Lectures, practical classes, laboratory work, elements of project learning	Project-oriented learning, problem-based learning, research methods
Technological component	Partial use of digital technologies, limited access to modern equipment	Wide use of digital platforms, simulations, modern laboratory equipment
Activity component	Solving problems, performing laboratory work, course projects	Research activities, internships, participation in startups and scientific projects
Assessment component	Exams, tests, tests, knowledge assessment	Assessment by learning outcomes: portfolio, projects, presentations, peer-review
Result component	Formed theoretical knowledge, basic research skills	Comprehensive STEM competence, readiness for professional activity

The conceptual model for the formation of students' subject competence in physics in STEM education in higher education institutions in Ukraine and USA is a multi-component system that covers target, content, methodological, technological, activity, evaluation and result aspects of the educational process (see Table 2).

First of all, the target component of the model determines the strategic guidelines for student training. In Ukraine, it focuses on the formation of fundamental knowledge in physics and the development of scientific thinking, while in the USA the emphasis is shifted to the formation of comprehensive STEM competencies focused on practical application and labor market needs.

An important role is played by the regulatory framework that determines the framework for the implementation of the educational process. In Ukraine, it is represented by national documents that regulate the development of STEM education and higher education in general. In the USA, regulatory support is more extensive and includes accreditation standards, recommendations of professional associations and state initiatives in the field of STEM.

The content component of the model reflects the structure of educational material. The Ukrainian system is traditionally based on classical physics sections with the gradual introduction of interdisciplinary elements. In contrast, in the USA, the content of education is integrated and combines physics with programming, engineering and data analysis.

The methodological component determines the approaches to the organization of education. In Ukraine, traditional forms of education (lectures, practical and laboratory classes) with partial use of project methods prevail. In the USA, innovative approaches are widely used, in particular problem-based learning, project-oriented learning and research methods.

No less important is the technological component, which reflects the level of use of digital resources and equipment. In Ukraine, this component is at the stage of development and is often limited by the resources of a particular educational institution. In the USA, it is characterized by a high level of technological integration, including the use of modern laboratories, simulations and digital platforms.

The activity component is associated with the practical implementation of knowledge. In Ukrainian higher education institutions, it is represented mainly by the performance of laboratory work, solving problems and course projects. In the USA, the activity component is more applied in nature and includes students' participation in scientific research, internships, startups and interdisciplinary projects.

The assessment component demonstrates approaches to determining the level of competence formation. In Ukraine, exams and control forms of knowledge testing traditionally dominate. In the USA, assessment is based on the achievement of learning outcomes and includes portfolios, project work, presentations and peer evaluation.

The result component is the outcome component, which reflects the final results of training. In Ukraine, this is, first of all, formed theoretical knowledge and basic research skills. In the USA, the result is formed complex STEM competence that ensure readiness for professional activity in a high-tech environment.

Separately, it is worth highlighting the professional orientation, which in Ukraine is traditionally aimed at scientific and pedagogical activities, while in the USA it covers a wide range of careers in STEM fields and involves close interaction with industry.

Thus, a comparative analysis of the model shows that the Ukrainian system has a strong theoretical basis, but requires further development in the direction of practical orientation, technologization and integration with international standards, which has already been effectively implemented in the USA.

Table 3 presents the characteristics of the main components of students' subject competence in physics in STEM education in Ukraine and USA.

Table 3

Component composition of students' subject competence in physics in STEM education in higher education institutions in Ukraine and USA

Competence category	Ukraine	USA
Fundamental knowledge of physics	Knowledge of classical sections of physics + integration with engineering problems (often depends on the university program)	Comprehensive coverage of mechanics, electromagnetism, quantum physics, thermodynamics according to learning outcomes
Analytical skills	Solving physical problems, but their practical application is often limited due to access to equipment / laboratories	Deep analytics, modeling, mathematical modeling of phenomena, data evaluation in real situations
Research skills	Projects and laboratories develop scientific thinking, but often without clear standardized assessment	Emphasis on independent research, experimental design, data processing, participation in grant research
Computational competence	Partially included, but heterogeneously, depends on the program (ICT/digital skills in STEM are still in the expansion stage)	High integration of programming, numerical modeling, data analysis in physics courses
Soft skills (communication, teamwork)	Emphasis on soft skills begins in STEAM projects/workshops, but it is not a mandatory component of all physics programs	Clearly emphasized in learning outcomes: presentations, publications, group work, scientific communications
Professional orientation	Orientation towards a scientific career or teaching (physics as a fundamental education)	Physics prepares for a wide range of careers: R&D, IT, energy, finance etc., with the inclusion of internships and practicums

Generalization of the main of students' subject competence in physics in STEM education in higher education institutions in Ukraine and USA allows us to identify several key components that form the holistic training of a modern specialist in the field of natural sciences (see Table 3).

These include fundamental knowledge, analytical, research, computational competence, as well as soft skills and professional orientation.

First of all, fundamental knowledge in physics forms the basis of subject competence. They include a deep understanding of the basic laws and theories of classical and modern physics. In Ukrainian higher education institutions, this component is characterized by a high level of theoretical training, while in the USA it is combined with practical application and clearly defined learning outcomes.

An important component is analytical competence, which include the ability to mathematically model, solve problems and interpret physical phenomena. In Ukraine, the emphasis is on traditional problem-solving, while in the USA, methods of real-world data analysis, computer modeling, and interdisciplinary approaches are more widely used.

Component of research competence reflect students' ability to conduct experiments, formulate hypotheses, and analyze results. In the Ukrainian system, they are formed mainly through laboratory and coursework, but in the USA, this activity is more systemic, including student participation in scientific projects, grants, and interuniversity research.

Computational competence which involves the use of modern digital tools, programming, and numerical methods, are becoming increasingly important. In the USA, these skills are integrated into most physical courses and are mandatory, while in Ukraine, their implementation is uneven and depends on the educational program.

A separate group is made up of social and communicative competence (soft skills), which include the ability to work in a team, carry out scientific communication, and present research results. In the USA, these skills are an integral part of educational outcomes, while in Ukraine they are formed mainly within individual projects and are not always systemic in nature.

The final element is professional orientation, which determines the readiness of the graduate for implementation in the STEM field. In Ukrainian practice, it is often limited to scientific and pedagogical activities, while in the USA, training is focused on a wide range of careers, including engineering, IT, analytics, and innovative industries.

The decentralized US educational system, where standards depend on a specific university or program (although national frameworks also exist) and a significant difference in the preparation of applicants, namely, the different level of previous school affects the success of US students in physics programs, which forces faculties to develop supporting courses, is a certain challenge and limitation in the acquisition of physics competence in US universities.

Therefore, the analysis shows that the structure of students' subject competence in physics in STEM education in higher education institutions in Ukraine and USA is similar in both countries, but differs in the level of practical implementation, integration of modern technologies, and orientation to the needs of the labor market.

The formation of students' subject competence in physics in the context of STEM education is a complex multidimensional process that combines fundamental scientific training, the development of research skills, computational skills and socio-communicative competence, and depends on educational policy, resource provision and methodological approaches.

It was found that STEM education is an effective tool for the modernization of physics education, ensuring the integration of knowledge in physics, mathematics, engineering and information technologies. This contributes to the formation of a holistic scientific worldview of students, the development of critical thinking, the ability to solve complex interdisciplinary tasks and adaptation to modern challenges of a technological society. The analysis of regulatory and legal support showed that in Ukraine the formation of students' subject competence in physics in STEM education is mainly centralized and is regulated by state education standards, national qualifications frameworks and strategic documents for the development of STEM education. At the same time, the USA has a decentralized model in which professional organizations, accreditation agencies and university autonomy play a key role, which allows for rapid adaptation of educational programs to the needs of the labor market and scientific and technological development.

A comparative analysis has shown that the Ukrainian higher education system is characterized by a strong fundamental training in physics, which ensures in-depth mastery of theoretical knowledge. However, its weaknesses remain insufficient practical orientation of training, limited integration of computing technologies, uneven implementation of STEM approaches and limited opportunities for the implementation of students' research activities.

In contrast, in US model of forming of students' subject competence in physics in STEM education in higher education institutions is more flexible, practice-oriented and technologically rich. It is based on clearly defined learning outcomes, active use of project and research learning, integration of programming and data analysis, as well as close cooperation with industry. This ensures the formation of comprehensive competence that meet the requirements of the modern labor market and contribute to the professional mobility of graduates.

It was established that both educational systems are guided by international framework documents and global trends in the development of education, in particular the recommendations of international organizations that focus on the development of 21st century competencies, interdisciplinarity, digitalization and lifelong learning. This creates the prerequisites for the unification of approaches to the formation of students' subject competence in physics in STEM education in the global educational space.

Based on the generalization of the research results, the feasibility of modernizing the system of training students in physics in Ukraine was substantiated by developing clear standards of students' subject competence in physics in STEM education in higher education institutions, strengthening practice-oriented learning, integrating computing technologies and digital tools into the educational process, expanding the possibilities of students' research activities, as well as intensifying cooperation between higher education institutions with scientific institutions and employers.

A comparative analysis formation of students' subject competence in physics in STEM education in higher education institutions in Ukraine and USA shows that the Ukrainian system has a strong fundamental foundation, but requires further modernization in the direction of practical orientation, digitalization and integration with international standards. The lack of a standard framework document that would clearly formulate of students' subject competence in physics in STEM education in higher education institutions in Ukraine, limited laboratory resources, limited access to the latest equipment and software, military conflict and the impossibility of fully integrating international experience into all universities, all this creates the challenges and limitations for Ukraine. Increasing the effectiveness of the formation of students' subject competence in physics in STEM education in higher education institutions is possible provided that fundamental scientific training is harmoniously combined with innovative educational technologies and an orientation to practical results. The use of best practices from the USA will contribute to improving the quality of specialist training and their competitiveness in the global labor market.

Bibliography

1. Батюк Л. В. Вища освіта США: історико-ретроспективний аналіз, тенденції та статистика. *Педагогічні науки: теорія та практика*. 2025a. № 3(55). С. 9–26. DOI: https://doi.org/10.26661/2786-5622-2025-3-01

2. Батюк Л. В., Жерновникова О. А. Ґенезис математичної освіти в Сполучених Штатах Америки в другій половині XX століття – 20-х роках XXI століття. *Теорія та методика навчання та виховання.* 2025. № 59. С. 38–73. DOI: https://doi.org/10.34142/23128046.2025.59.03

3. Бугров В., Гожик А., Жданова К., Зарубінська І., Захарченко В., Калашнікова С., Козієвська О., Линьова І., Луговий В., Оржель О., Рашкевич Ю., Таланова Ж., Шитікова С. Правові засади реалізації Болонського процесу в Україні : монографія / за заг. ред. В. Лугового, С. Калашнікової / К. : ДП «НВЦ «Пріоритети», 2014. 156 с.

4. Закон України «Про вищу освіту»: прийнятий 2014 року № 37-38, ст. 2004. *Відомості Верховної Ради України (ВВР)*. Документ 1556-VII, чинний, поточна редакція – Визнання конституційними окремих положень від 11.03.2026, підстава – va02p710-26. URL: https://zakon.rada.gov.ua/laws/show/1556-18#Text

5. Закон України «Про внесення змін до деяких законів України щодо вдосконалення освітньої діяльності у сфері вищої освіти»: прийнятий 2020 року, № 24, ст. 170. *Відомості Верховної Ради України (ВВР)*. URL: https://zakon.rada.gov.ua/laws/show/392-20#n6

6. Закон України «Про освіту»: прийнятий 2017 року, № 38-39, ст. 380. *Відомості Верховної Ради (ВВР).* Документ 2145-VIII, чинний, поточна редакція від 01.01.2026, підстава – 4695-IX. URL: https://zakon.rada.gov.ua/laws/show/2145-19#Text

7. Затверджені стандарти вищої освіти. 2026. URL: https://mon.gov.ua/osvita-2/vishcha-osvita-ta-osvita-doroslikh/naukovo-metodichna-rada-ministerstva-osviti-i-nauki-ukraini/zatverdzheni-standarti-vishchoi-osviti

8. Захарченко В. М., Міюсов М. В., Парменова Д. Г. Рамки кваліфікацій у Європейському освітньому просторі : навчально-методичний посібник. Одеса : НУ «ОМА», 2017. 88 с.

9. Методичні рекомендації щодо розроблення стандартів вищої освіти : Наказ Міністерства освіти і науки України від 01 червня 2017 № 600. URL: https://mon.gov.ua/static-objects/mon/sites/1/vishcha-osvita/proekty%20standartiv%20vishcha%20osvita/1648.pdf?__cf_chl_tk=QdTc9LnfUpA91p1FsFOT39.XGxKoZiCmMMO9jaN480g-1775919641-1.0.1.1-fY.ZOJWttvRFDW9fF29Z6oBeFIsxFTxk.fspENnlsuo

10. Національна рамка кваліфікацій (НРК) : постанова Кабінету Міністрів України від 23 листопада 2011 р. № 1341; в редакції постанови Кабінету Міністрів України від 25 червня

2020 р. № 519. URL: https://enic.in.ua/attachments/article/270/NQFU__e42d069b-d8df-450a-836e-efff874015a9.pdf

11. Національна рамка кваліфікацій. 2026. *Національне Агентство Кваліфікацій*. URL: https://nqa.gov.ua/national-qualification-frame/

12. Про затвердження Методичних рекомендацій щодо розроблення стандартів вищої освіти : Наказ Міністерства освіти і науки України від 27.03.2025 № 512. URL: https://mon.gov.ua/static-objects/mon/sites/1/vishcha-osvita/2025/03/27/nakaz-mon-512-vid-27-03-2025.pdf

13. Про затвердження Методичних рекомендацій щодо розроблення стандартів професійної (професійно-технічної) освіти за компетентнісним підходом : Наказ Міністерства освіти і науки України, документ v0216729-21, поточна редакція від 17.02.2021 р. № 216. URL: https://zakon.rada.gov.ua/rada/show/v0216729-21#Text

14. Про затвердження Національної рамки кваліфікацій : Постанова Кабінету Міністрів України від 23 листопада 2011 р. № 1341. Документ 1341-2011-п, чинний, поточна редакція від 07.02.2026, підстава – 159-2026-п. URL: https://zakon.rada.gov.ua/laws/show/1341-2011-%D0%BF#Text

15. Про затвердження плану заходів щодо реалізації Концепції розвитку природничо-математичної освіти (STEM-освіти) до 2027 року : Розпорядження Кабінету Міністрів України від 13 січня 2021 р. № 131-р. Документ 131-2021-р, чинний, поточна редакція від 13.01.2021. URL: https://zakon.rada.gov.ua/laws/show/131-2021-%D1%80#Text

16. Про затвердження Положення про акредитацію освітніх програм, за якими здійснюється підготовка здобувачів вищої освіти : Наказ Міністерства освіти і науки України від 15.05.2024 р. № 686. Документ z1013-24, чинний, поточна редакція від 15.05.2024. URL: https://zakon.rada.gov.ua/laws/show/z1013-24#Text

17. Про схвалення Концепції розвитку природничо-математичної освіти (STEM-освіти) : Розпорядження Кабінету Міністрів України від 5 серпня 2020 р. № 960-р. Документ 960-2020-р, чинний, поточна редакція від 05.08.2020. URL: https://zakon.rada.gov.ua/laws/show/960-2020-%D1%80#Text

18. Про схвалення Стратегії розвитку вищої освіти в Україні на 2022–2032 роки : Розпорядження Кабінету Міністрів України від 23 лютого 2022 р. № 286-р. Документ 286-2022-р, чинний, поточна редакція від 06.01.2026, підстава – 1796-2025-п. URL: https://zakon.rada.gov.ua/laws/show/286-2022-%D1%80#Text

19. Про утворення Національного координаційного центру Європейської рамки кваліфікацій для навчання впродовж життя в Україні : Рішення Національного Агентства Кваліфікацій від 17.03.2023 р. протокол № 8(108). Київ, 2023. 10 с. URL: https://drive.google.com/file/d/1DTlgrlyOb4ym0chOxervE8YPOvtwz1ib/view

20. Рамка цифрової компетентності громадян України. *DigCompUA for Citizens 2.2*. 2023. 105 с. URL: https://osvita.diia.gov.ua/uploads/1/7451-ramka_cifrovoi_kompetentnosti.pdf

21. Рашкевич Ю. М. Методичні рекомендації для розроблення профілів ступеневих програм, включаючи програмні компетентності та програмні результати навчання / пер. з англ. Національного експерта з реформування вищої освіти Програми Еразмус+, д-ра техн. наук, проф. Ю. М. Рашкевича. Київ : ТОВ «Поліграф плюс», 2016. 80 с. URL: https://erasmusplus.org.ua/images/phocadownload/HERE_doc/ProgramnyiProfil_Tuning_HERE.pdf

22. Сороко Н. В., Шимон О. М. Готовність учителів до використання цифрових інструментів у STEAM-орієнтованому освітньому середовищі. *Освітня аналітика України*. 2025. № 1(33). С. 28–42. DOI: https://doi.org/10.32987/2617-8532-2025-1-28-42

23. Хайдарі Н. І., Заслужена А. А., Юхновець Н. П. Європейські стандарти вищої освіти в Україні: Болонський вимір. *Інноваційна педагогіка*. 2024. Вип. 68. Т. 2. С. 20–23. DOI: https://doi.org/10.32782/2663-6085/2024/68.2.3

24. Accredited Programs. 2026. URL: https://amspub.abet.org/aps/name-search?searchType=institution

25. AIP. *American Institute of Physics*. 2026. URL: https://www.aip.org/american-association-of-physics-teachers?gad_source=1&gad_campaignid=23631141274&gbraid=0AAAAADiNja-o3n8snLxHiRcQmmqgiQH0W0&gclid=Cj0KCQjwv-LOBhCdARIsAM5hdKeaeAYn86qEPvcHur-Fl4lFJUYFxBx1vsKw3Yz4o8xtCzcCVDGLuenEaAoXKEALw_wcB

26. American Physical Society. *Improving Undergraduate Physics Education (IUPE) Award*. 2026. URL: https://www.aps.org/funding-recognition/award/improving-undergraduate-physics-education

27. A STEM Education Strategic Plan: skills for competitiveness and innovation. *Communication from the commission to the European parliament, the Council, THE European economic and social committee and the committee of the regions*. Brussels, 2025. 13 p. URL: https://education.ec.europa.eu/sites/default/files/2025-03/STEM_Education_Strategic_Plan_COM_2025_89_1_EN_0.pdf

28. Barna O. V., Kuzminska O. H., Semerikov S. O. Enhancing digital competence through STEM-integrated universal design for learning: a pedagogical framework for computer science education in Ukrainian secondary schools. *Discover Education.* 2025. Vol. 4. Art. no. 357. DOI: https://doi.org/10.1007/s44217-025-00821-y

29. Batyuk L. Major aspects of STEM education based on U.S. government initiatives. *Educational Challenges*. 2025b. Vol. 30(1). P. 88–105. DOI: https://doi.org/10.34142/2709-7986.2025.30.1.06

30. Batyuk L. Thematic component of STEM education in legislative and regulatory documents in the field of education and science of Ukraine and the United States of America. *The Scientific Issues of Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. Section: Pedagogics and Psychology*. 2026a. Vol. 85. P. 110–120. DOI: https://doi.org/10.31652/2415-7872-2026-85-110-120

31. Batyuk L. Traditional and innovative technologies in teachers' professional competence in training the students in STEM education. *Collection of research papers «Pedagogical sciences»*. 2025c. Vol. 110. P. 7–15. DOI: https://doi.org/10.32999/ksu2413-1865/2025-110-1

32. Batyuk L. V. Digital integration of physics in STEM education in pedagogical universities in the USA and Ukraine. *Цифрова трансформація освіти та науки: матеріали IV Всеукр. наук.-практ. конф*. Харків, 2026b. С. 29–35. DOI: https://doi.org/10.5281/zenodo.19119397

33. Batyuk L. V., Masych V. V. A review of the implementation of STEM education in the USA based on robotics. *Problems of Engineering Pedagogic Education*. 2025a. Vol. 84. P. 464–474. DOI: https://doi.org/10.26565/2074-8922-2025-84-40

34. Batyuk L., Masych V. Features of Modern Higher Education in the USA: STEM Education. *Educological Discourse*. 2025b. Vol. 50(3). P. 26–39. DOI: https://doi.org/10.28925/2312-5829/2025.3.3

35. Batyuk L., Zhernovnykova O. Strategy for the development of digital competence in the national education system of Ukrainian society. *Journal of Education, Health and Sport*. 2018. Vol. 8(11). P. 912–921. DOI: https://doi.org/10.12775/JEHS.2018.8.11.087

36. Boichenko V., Boichenko M. STEM Education in the USA and Ukraine: Comparative Analysis. *Педагогічні науки: теорія, історія, інноваційні технології: науковий журнал*. 2019. № 5(89). С. 3–13. DOI: https://doi.org/10.24139/2312-5993/2019.05/003-013

37. Bondarenko V., Kryvylova O. Model of formation of innovative competence of students of basic general secondary education in the process of learning physics. *ScienceRise: Pedagogical Education*. 2024. Vol. 4(61). P. 54–60. DOI: https://doi.org/10.15587/2519-4984.2024.319432

38. Calmer J. Teaching Physics within a Next Generation Science Standards Perspective. *Pedagogical Research.* 2019. Vol. 4(4). P. 1–6. DOI: https://doi.org/10.29333/pr/5868

39. Cosgrove J., Cachia R. DigComp 3.0 – European Digital Competence Framework. Fifth edition. Luxembourg : Publications Office of the European Union, 2025. 123 p. DOI: https://doi.org/10.2760/0001149

40. DeCoito I., Fazio X., Gichuru J. STEM Education: International Perspectives in STEM Education. *Global Perspectives on STEM Education*. Springer, Cham, 2024. P. 93–108. DOI: https://doi.org/10.1007/978-3-031-60676-2_6

41. Fischer H. E., Kauertz A. Professional Competencies for Teaching Physics. Fischer, H. E., Girwidz, R. (Eds.), *Physics Education. Challenges in Physics Education.* Springer, Cham, 2021. P. 25–53. DOI: https://doi.org/10.1007/978-3-030-87391-2_2

42. Hestenes D., Megowan-Romanowicz C., Popp S. E. O., Jackson J., Culbertson R. J. A graduate program for high school physics and physical science teachers. *American Journal of Physics*. 2011. Vol. 79(9). P. 971–979. DOI: https://doi.org/10.1119/1.3602122

43. OECD future of education and skills 2030: OECD learning compass 2030. A Series of Concept Notes. OECD Publishing, 2019. 146 p. URL: https://www.oecd.org/content/dam/oecd/en/about/projects/edu/education-2040/1-1-learning-compass/OECD_Learning_Compass_2030_Concept_Note_Series.pdf

44. OECD (2023). PISA 2022 Results (Volume I): The State of Learning and Equity in Education. Paris : PISA, OECD Publishing, 2023. 492 p. DOI: https://doi.org/10.1787/53f23881-en

45. Otero V. A brief history of physics education in the United States. *American Journal of Physics*. 2015. Vol. 83, № 5. P. 447–458. DOI: https://doi.org/10.1119/1.4902397

46. Physics and 21st Century Science Standards: The Role of Physics in the NGSS*. American Association of Physics Teachers, 2017. 26 p. URL: https://alapex.org/mediawiki/images/b/bf/Physics_in_the_NGSS.pdf

47. Physics in 21st Century Science Standards: The Role of Physics in the NGSS*. American Association of Physics Teachers, 2026. URL: https://www.aapt.org/k12/Physics-in-21st-Century-Science-Standards.cfm

48. Phys21: Preparing Physics Students for 21st Century Careers. American Physical Society, 2016. 82 p. URL: https://www.compadre.org/jtupp/docs/J-Tupp_Report.pdf

49. Rajapaksha A., Hirsch A. S. Competency based teaching of college physics: The philosophy and the practice. *Physical Review Physics Education Research*. 2017. Vol. 13. P. 1–12. DOI: https://doi.org/10.1103/PhysRevPhysEducRes.13.020130

50. Sala A., Punie Y., Garkov V., Cabrera M. LifeComp: The European framework for personal, social and learning to learn key competence. Publications Office of the European Union, 2020. 76 p. DOI: https://doi.org/10.2760/302967

51. Science Education in the United States: Standards and Challenges. 2026. URL: https://thescienceauthority.com/science-education-in-the-us

52. Setting the National Standard for Undergraduate Physics Education. Morgan State University, 2026. URL: https://www.morgan.edu/news/setting-the-national-standard-for-undergraduate-physics-education

53. Stukalo N., Trebenko O., Knysh O., Shylina A. Self-Assessment Report of the National Agency for Higher Education Quality Assurance 2025 (SAR). Kyiv : National Agency for Higher Education Quality Assurance, 2025. 93 p. URL: https://naqa.gov.ua/wp-content/uploads/2025/08/SAR-2025.pdf

54. The European Qualifications Framework. European Union, 2026. URL: https://europass.europa.eu/en/european-qualifications-framework-eqf

55. The framework of qualifications for the European Higher Education Area. 2018. 2 p. URL: https://ehea.info/media.ehea.info/file/BFUG_Meeting/49/6/BFUG_BG_SR_61_4c_AppendixIII_947496.pdf

56. The State of State Science Standards. Thomas B. Fordman Institute, 2012. 217 p. URL: https://files.eric.ed.gov/fulltext/ED528964.pdf

57. Vuorikari R., Kluzer S., Punie Y. DigComp 2.2: The digital competence framework for citizens. Publications Office of the European Union, 2022. 134 p. DOI: https://doi.org/10.2760/115376

58. Science diplomacy in a rapidly changing world: Building peace in the minds of men and women: Report on the UNESCO Global Ministerial Dialogue on Science Diplomacy. *UNESCO*, 2025. 40 p. DOI: https://doi.org/10.54677/DTIP7777

References

1. Batyuk, L. V. (2025a). Vyshcha osvita SShA: istoryko-retrospektyvnyi analiz, tendentsii ta statystyka [Higher education in the USA: a historical and retrospective analysis, trends and statistics]. *Pedahohichni nauky: teoriia ta praktyka – Pedagogical sciences: theory and practice, 3*(55), 9–26. DOI: https://doi.org/10.26661/2786-5622-2025-3-01 [in Ukranian].

2. Batyuk, L. V., & Zhernovnykova, O. A. (2025). Genezys matematychnoi osvity v Spoluchenykh Shtatakh Ameryky v druhii polovyni XX stolittia – 20-kh rokakh XXI stolittia [The genesis of mathematical education in the United States of America in the second half of the 20th century – the 20s of the 21st century]. *Teoriia ta metodyka navchannia ta vykhovannia – Theory and methods of teaching and upbringing, (59),* 38–73. DOI: https://doi.org/10.34142/23128046.2025.59.03 [in Ukranian].

3. Bugrov, V., Gozhyk, A., Zhdanova, K., Zarubinska, I., Zakharchenko, V., Kalashnikova, S., Koziyevska, O., Lynyova, I., Lugovyi, V., Orzhel, O., Rashkevych, Yu., Talanova, Zh., & Shytikova, S. (2014). Pravovi zasady realizatsii Bolonskoho protsesu v Ukraini – Legal principles of implementing the Bologna process in Ukraine. Kyiv: State Enterprise «NVC «Priority» [in Ukranian].

4. Zakon Ukrainy «Pro vyshchu osvitu» pryiniatyi 2014 roku, № 37-38, st. 2004 [Law of Ukraine «On Higher Education» from 2014, № 37-38, st. 2004]. *Vidomosti Verkhovnoi Rady Ukrainy – Bulletin of Verkhovna Rady Ukraine.* Dokument 1556-VII, chynnyi, potochna redaktsiia – Vyznannia konstytutsiinymy okremykh polozhen vid 11.03.2026, pidstava – va02p710-26. (2026). URL: https://zakon.rada.gov.ua/laws/show/1556-18#Text [in Ukranian].

5. Zakon Ukrainy «Pro vnesennia zmin do deiakykh zakoniv Ukrainy shchodo vdoskonalennia osvitnoi diialnosti u sferi vyshchoi osvity» pryiniatyi 2020 roku, № 24, st. 170 [Law of Ukraine «On Amendments to Certain Laws of Ukraine on Improving Educational Activities in the Sphere of Higher Education» from 2020, № 24, st. 170]. *Vidomosti Verkhovnoi Rady Ukrainy – Bulletin of Verkhovna Rady Ukraine.* (2020). URL: https://zakon.rada.gov.ua/laws/show/392-20#n6 [in Ukranian].

6. Zakon Ukrainy «Pro osvitu» pryiniatyi 2017, № 38-39, st. 380 [Law of Ukraine «On Education» from 2017, № 38-39, st. 380]. *Vidomosti Verkhovnoi Rady Ukrainy – Bulletin of Verkhovna Rady Ukraine.* Dokument 2145-VIII, chynnyi, potochna redaktsiia vid 01.01.2026, pidstava – 4695-IX. (2026). URL: https://zakon.rada.gov.ua/laws/show/2145-19#Text [in Ukranian].

7. Zatverdzheni standarty vyshchoi osvity [Approved standards of higher education]. (2026). URL: https://mon.gov.ua/osvita-2/vishcha-osvita-ta-osvita-doroslikh/naukovo-metodichna-rada-ministerstva-osviti-i-nauki-ukraini/zatverdzheni-standarti-vishchoi-osviti [in Ukranian].

8. Zakharchenko, V. M., Miyusov, M. V., & Parmenova, D. G. (2017). Ramky kvalifikatsii u Yevropeiskomu osvitnomu prostori [Qualifications Framework in the European Educational Space]. Odesa: NU «OMA» [in Ukranian].

9. Metodychni rekomendatsii shchodo rozroblennia standartiv vyshchoi osvity: Nakaz Ministerstva osvity i nauky Ukrainy vid 01 chervnia 2017 № 600 [Methodological recommendations for the development of higher education standards: Order of the Ministry of Education and Science of Ukraine dated June 1, 2017 No. 600]. (2017). URL: https://mon.gov.ua/static-objects/mon/sites/1/vishcha-osvita/proekty%20standartiv%20vishcha%20osvita/1648.pdf?__cf_chl_tk=QdTc9LnfUpA91p1FsFOT39.XGxKoZiCmMMO-9jaN480g-1775919641-1.0.1.1-fY.ZOJWttvRFDW9fF29Z6oBeFIsxFTxk.fspENnlsuo [in Ukranian].

10. Natsionalna ramka kvalifikatsii (NRK): postanova Kabinetu Ministriv Ukrainy vid 23 lystopada 2011 r. № 1341; v redaktsii postanovy Kabinetu Ministriv Ukrainy vid 25 chervnia 2020 r. № 519 [National Qualifications Framework (NQF): resolution of the Cabinet of Ministers of Ukraine dated November 23, 2011 No. 1341; as amended by the resolution of the Cabinet of Ministers of Ukraine dated June 25, 2020 No. 519]. (2020). URL: https://enic.in.ua/attachments/article/270/NQFU__e42d069b-d8df-450a-836e-efff874015a9.pdf [in Ukranian].

11. Natsionalna ramka kvalifikatsii [National Qualifications Framework]. (2026). *Natsionalne Ahentstvo Kvalifikatsii – National Qualifications Agency*. URL: https://nqa.gov.ua/national-qualification-frame/ [in Ukranian].

12. Pro zatverdzhennia Metodychnykh rekomendatsii shchodo rozroblennia standartiv vyshchoi osvity: Nakaz Ministerstva osvity i nauky Ukrainy vid 27.03.2025 № 512 [On approval of Methodological recommendations for the development of higher education standards: Order of the Ministry of Education and Science of Ukraine dated March 27, 2025 No. 512]. (2025). URL: https://mon.gov.ua/static-objects/mon/sites/1/vishcha-osvita/2025/03/27/nakaz-mon-512-vid-27-03-2025.pdf [in Ukranian].

13. Pro zatverdzhennia Metodychnykh rekomendatsii shchodo rozroblennia standartiv profesiinoi (profesiino-tekhnichnoi) osvity za kompetentnisnym pidkhodom: Nakaz Ministerstva osvity i nauky Ukrainy, dokument v0216729-21, potochna redaktsiia vid 17.02.2021 r. № 216 [On approval of Methodological recommendations for the development of standards of vocational (vocational and technical) education using a competency-based approach: Order of the Ministry of Education and Science of Ukraine, document v0216729-21, current edition dated February 17, 2021 No. 216]. (2021). URL: https://zakon.rada.gov.ua/rada/show/v0216729-21#Text [in Ukranian].

14. Pro zatverdzhennia Natsionalnoi ramky kvalifikatsii: Postanova Kabinetu Ministriv Ukrainy vid 23 lystopada 2011 r. № 1341. Dokument 1341-2011-p, chynnyi, potochna redaktsiia vid 07.02.2026, pidstava – 159-2026-p [On approval of the National Qualifications Framework: Resolution of the Cabinet of Ministers of Ukraine dated November 23, 2011 № 1341. Document 1341-2011-p, valid, current edition dated 02.07.2026, basis – 159-2026-p]. (2026). URL: https://zakon.rada.gov.ua/laws/show/1341-2011-%D0%BF#Text [in Ukranian].

15. Pro zatverdzhennia planu zakhodiv shchodo realizatsii Kontseptsii rozvytku pryrodnycho-matematychnoi osvity (STEM-osvity) do 2027 roku: Rozporiadzhennia Kabinetu Ministriv Ukrainy vid 13 sichnia 2021 r. № 131-r. Dokument 131-2021-r, chynnyi, potochna redaktsiia vid 13.01.2021 [On approval of the action plan for the implementation of the Concept for the Development of Science and Mathematics Education (STEM Education) until 2027: Decree of the Cabinet of Ministers of Ukraine dated January 13, 2021 № 131-r. Document 131-2021, valid, current edition dated January 13, 2021]. (2021). URL: https://zakon.rada.gov.ua/laws/show/131-2021-%D1%80#Text [in Ukranian].

16. Pro zatverdzhennia Polozhennia pro akredytatsiiu osvitnikh prohram, za yakymy zdiisniuietsia pidhotovka zdobuvachiv vyshchoi osvity: Nakaz Ministerstva osvity i nauky Ukrainy vid 15.05.2024 r. № 686. Dokument z1013-24, chynnyi, potochna redaktsiia vid 15.05.2024 [On approval of the Regulations on accreditation of educational programs for training higher education applicants: Order of the Ministry of Education and Science of Ukraine dated May 15, 2024 No. 686. Document z1013-24, valid, current edition dated May 15, 2024]. (2024). URL: https://zakon.rada.gov.ua/laws/show/z1013-24#Text [in Ukranian].

17. Pro skhvalennia Kontseptsii rozvytku pryrodnycho-matematychnoi osvity (STEM-osvity): Rozporiadzhennia Kabinetu Ministriv Ukrainy vid 5 serpnia 2020 r. № 960-r. Dokument 960-2020-r, chynnyi, potochna redaktsiia vid 05.08.2020 [On approval of the Concept for the development of natural and mathematical education (STEM education): Decree of the Cabinet of Ministers of Ukraine dated August 5, 2020 No. 960-r. Document 960-2020, valid, current edition dated August 5, 2020]. (2020). URL: https://zakon.rada.gov.ua/laws/show/960-2020-%D1%80#Text [in Ukranian].

18. Pro skhvalennia Stratehii rozvytku vyshchoi osvity v Ukraini na 2022–2032 roky: Rozporiadzhennia Kabinetu Ministriv Ukrainy vid 23 liutoho 2022 r. № 286-r. Dokument 286-2022-r, chynnyi, potochna redaktsiia vid 06.01.2026, pidstava – 1796-2025-p [On approval of the Strategy for the Development of Higher Education in Ukraine for 2022–2032: Decree of the Cabinet of Ministers of Ukraine dated February 23, 2022 No. 286-r. Document 286-2022, valid, current edition dated January 6, 2026, basis – 1796-2025-p]. (2026). URL: https://zakon.rada.gov.ua/laws/show/286-2022-%D1%80#Text [in Ukranian].

19. Pro utvorennia Natsionalnoho koordynatsiinoho tsentru Yevropeiskoi ramky kvalifikatsii dlia navchannia vprodovzh zhyttia v Ukraini: Rishennia Natsionalnoho Ahentstva Kvalifikatsii vid

17.03.2023 r. protokol № 8(108) [On the establishment of the National Coordination Center of the European Qualifications Framework for Lifelong Learning in Ukraine: Decision of the National Qualifications Agency dated March 17, 2023, protocol No. 8(108)]. (2023). Kyiv. URL: https://drive.google.com/file/d/1DTlgrlyOb4ym0chOxervE8YPOvtwz1ib/view [in Ukranian].

20. Ramka tsyfrovoi kompetentnosti hromadian Ukrainy [Digital Competence Framework for Citizens of Ukraine]. (2023). *DigCompUA for Citizens 2.2. – DigCompUA for Citizens 2.2.* URL: https://osvita.diia.gov.ua/uploads/1/7451-ramka_cifrovoi_kompetentnosti.pdf [in Ukranian].

21. Rashkevych, Yu. M. (2016). Metodychni rekomendatsii dlia rozroblennia profiliv stupenevykh prohram, vkliuchaiuchy prohramni kompetentnosti ta prohramni rezultaty navchannia [Methodological recommendations for the development of profiles of degree programs, including program competencies and program learning outcomes]. Transl. z English Yu. M. Rashkevych. Kyiv: TOV «Polihraf plius». URL: https://erasmusplus.org.ua/images/phocadownload/HERE_doc/ProgramnyiProfil_Tuning_HERE.pdf [in Ukranian].

22. Soroko, N. V., & Shymon, O. M. (2025). Hotovnist uchyteliv do vykorystannia tsyfrovykh instrumentiv u STEAM-oriientovanomu osvitnomu seredovyshchi [Teachers' readiness to use digital tools in a STEAM-oriented educational environmen]. *Osvitnia analityka Ukrainy – Educational Analytics of Ukraine, 1*(33), 28–42. DOI: https://doi.org/10.32987/2617-8532-2025-1-28-42 [in Ukranian].

23. Khaidari, N. I., Zasluzhena, A. A., & Yukhnovets, N. P. (2024). Yevropeiski standarty vyshchoi osvity v Ukraini: Bolonskyi vymir [European standards of higher education in Ukraine: Bologna dimension]. *Innovatsiina pedahohika – Innovative pedagogy, 68*(2), 20–23. DOI: https://doi.org/10.32782/2663-6085/2024/68.2.3 [in Ukranian].

24. Accredited Programs. (2026). URL: https://amspub.abet.org/aps/name-search?searchType=institution

25. AIP. (2026). *American Institute of Physics*. URL: https://www.aip.org/american-association-of-physics-teachers?gad_source=1&gad_campaignid=23631141274&gbraid=0AAAAADiNja-o3n8snLxHiRcQmmqgiQH0W0&gclid=Cj0KCQjwv-LOBhCdARIsAM5hdKeaeAYn86qEPvcHurFl4lFJUYFxBx1vsKw3Yz4o8xtCzcCVDGLuenEaAoXKEALw_wcB

26. American Physical Society. (2026). *Improving Undergraduate Physics Education (IUPE) Award*. URL: https://www.aps.org/funding-recognition/award/improving-undergraduate-physics-education

27. A STEM Education Strategic Plan: skills for competitiveness and innovation. Communication from the commission to the European parliament, the Council, THE European economic and social committee and the committee of the regions. (2025). Brussels. URL: https://education.ec.europa.eu/sites/default/files/2025-03/STEM_Education_Strategic_Plan_COM_2025_89_1_EN_0.pdf

28. Barna, O. V., Kuzminska, O. H., & Semerikov, S. O. (2025). Enhancing digital competence through STEM-integrated universal design for learning: a pedagogical framework for computer science education in Ukrainian secondary schools. *Discover Education, (4),* 357. DOI: https://doi.org/10.1007/s44217-025-00821-y

29. Batyuk, L. (2025b). Major aspects of STEM education based on U.S. government initiatives. *Educational Challenges, 30*(1), 88–105. DOI: https://doi.org/10.34142/2709-7986.2025.30.1.06

30. Batyuk, L. (2026a). Thematic component of STEM education in legislative and regulatory documents in the field of education and science of Ukraine and the United States of America. *The Scientific Issues of Vinnytsia Mykhailo Kotsiubynskyi State Pedagogical University. Section: Pedagogics and Psychology, (85),* 110–120. DOI: https://doi.org/10.31652/2415-7872-2026-85-110-120

31. Batyuk, L. (2025c). Traditional and innovative technologies in teachers' professional competence in training the students in STEM education. *Collection of research papers «Pedagogical sciences», (110),* 7–15. DOI: https://doi.org/10.32999/ksu2413-1865/2025-110-1

32. Batyuk, L. V. (2026b). Digital integration of physics in STEM education in pedagogical universities in the USA and Ukraine. *Tsyfrova transformatsiia osvity ta nauky – Digital transformation*

of education and science: materials of the 4th All-Ukrainian scientific and practical conference. (pp. 29–35). Kharkiv. DOI: https://doi.org/10.5281/zenodo.19119397

33. Batyuk, L. V., & Masych, V. V. (2025a). A review of the implementation of STEM education in the USA based on robotics. *Problems of Engineering Pedagogic Education, (84),* 464–474. DOI: https://doi.org/10.26565/2074-8922-2025-84-40

34. Batyuk, L., & Masych, V. (2025b). Features of Modern Higher Education in the USA: STEM Education. *Educological Discourse, 50*(3), 26–39. DOI: https://doi.org/10.28925/2312-5829/2025.3.3

35. Batyuk, L., & Zhernovnykova, O. (2018). Strategy for the development of digital competence in the national education system of Ukrainian society. *Journal of Education, Health and Sport, 8*(11), 912–921. DOI: https://doi.org/10.12775/JEHS.2018.8.11.087

36. Boichenko, V., & Boichenko, M. (2019). STEM Education in the USA and Ukraine: Comparative Analysis. *Pedahohichni nauky: teoriia, istoriia, innovatsiini tekhnolohii: naukovyi zhurnal – Pedagogical sciences: theory, history, innovative technologies: scientific journal, 5*(89), 3–13. DOI: https://doi.org/10.24139/2312-5993/2019.05/003-013

37. Bondarenko, V., & Kryvylova, O. (2024). Model of formation of innovative competence of students of basic general secondary education in the process of learning physics. *ScienceRise: Pedagogical Education, 4*(61), 54–60. DOI: https://doi.org/10.15587/2519-4984.2024.319432

38. Calmer, J. (2019). Teaching Physics within a Next Generation Science Standards Perspective. *Pedagogical Research, 4*(4), 1–6. DOI: https://doi.org/10.29333/pr/5868

39. Cosgrove, J., & Cachia, R. (2025). DigComp 3.0 – European Digital Competence Framework. Fifth edition. Luxembourg: Publications Office of the European Union, 2025. DOI: https://doi.org/10.2760/0001149

40. DeCoito, I., Fazio, X., & Gichuru, J. (2024). STEM Education: International Perspectives in STEM Education. In: *Global Perspectives on STEM Education*. (pp. 93–108). Springer, Cham. DOI: https://doi.org/10.1007/978-3-031-60676-2_6

41. Fischer, H. E., & Kauertz, A. (2021). Professional Competencies for Teaching Physics. In: Fischer, H. E., Girwidz, R. (Eds.), *Physics Education. Challenges in Physics Education.* (pp. 25–53). Springer, Cham, 2021. DOI: https://doi.org/10.1007/978-3-030-87391-2_2

42. Hestenes, D., Megowan-Romanowicz, C., Popp, S. E. O., Jackson, J., & Culbertson, R. J. (2011). A graduate program for high school physics and physical science teachers. *American Journal of Physics, 79*(9), 971–979. DOI: https://doi.org/10.1119/1.3602122

43. OECD future of education and skills 2030: OECD learning compass 2030. A Series of Concept Notes. (2019). OECD Publishing. URL: https://www.oecd.org/content/dam/oecd/en/about/projects/edu/education-2040/1-1-learning-compass/OECD_Learning_Compass_2030_Concept_Note_Series.pdf

44. OECD (2023). PISA 2022 Results (Volume I): The State of Learning and Equity in Education. Paris: PISA, OECD Publishing. DOI: https://doi.org/10.1787/53f23881-en

45. Otero, V. (2015). A brief history of physics education in the United States. *American Journal of Physics, 83*(5), 447–458. DOI: https://doi.org/10.1119/1.4902397

46. Physics and 21st Century Science Standards: The Role of Physics in the NGSS*. (2017). American Association of Physics Teachers. URL: https://alapex.org/mediawiki/images/b/bf/Physics_in_the_NGSS.pdf

47. Physics in 21st Century Science Standards: The Role of Physics in the NGSS*. (2026). American Association of Physics Teachers. URL: https://www.aapt.org/k12/Physics-in-21st-Century-Science-Standards.cfm

48. Phys21: Preparing Physics Students for 21st Century Careers. (2016). American Physical Society. URL: https://www.compadre.org/jtupp/docs/J-Tupp_Report.pdf

49. Rajapaksha, A., & Hirsch, A. S. (2017). Competency based teaching of college physics: The philosophy and the practice. *Physical Review Physics Education Research, (13),* 1–12. DOI: https://doi.org/10.1103/PhysRevPhysEducRes.13.020130

50. Sala, A., Punie, Y., Garkov, V., & Cabrera, M. (2020). LifeComp: The European framework for personal, social and learning to learn key competence. Publications Office of the European Union. DOI: https://doi.org/10.2760/302967

51. Science Education in the United States: Standards and Challenges. (2026). URL: https://thescienceauthority.com/science-education-in-the-us

52. Setting the National Standard for Undergraduate Physics Education. (2026). Morgan State University. URL: https://www.morgan.edu/news/setting-the-national-standard-for-undergraduate-physics-education

53. Stukalo, N., Trebenko, O., Knysh, O., & Shylina, A. (2025). Self-Assessment Report of the National Agency for Higher Education Quality Assurance 2025 (SAR). Kyiv: National Agency for Higher Education Quality Assurance. URL: https://naqa.gov.ua/wp-content/uploads/2025/08/SAR-2025.pdf

54. The European Qualifications Framework. (2026). European Union. URL: https://europass.europa.eu/en/european-qualifications-framework-eqf

55. The framework of qualifications for the European Higher Education Area. (2018). URL: https://ehea.info/media.ehea.info/file/BFUG_Meeting/49/6/BFUG_BG_SR_61_4c_AppendixIII_947496.pdf

56. The State of State Science Standards. (2012). Thomas B. Fordman Institute. URL: https://files.eric.ed.gov/fulltext/ED528964.pdf

57. Vuorikari, R., Kluzer, S., & Punie, Y. (2022). DigComp 2.2: The digital competence framework for citizens. Publications Office of the European Union. DOI: https://doi.org/10.2760/115376

58. UNESCO. (2025). Science diplomacy in a rapidly changing world: Building peace in the minds of men and women: Report on the UNESCO Global Ministerial Dialogue on Science Diplomacy. *UNESCO*. DOI: https://doi.org/10.54677/DTIP7777

Батюк Л. В., Масич В. В. Формування предметної компетентності студентів з фізики в умовах STEM-освіти в Україні та США

У статті здійснено компаративний аналіз формування предметної компетентності студентів з фізики в умовах отримання STEM-освіти у закладах вищої освіти України та США. Розкрито теоретичні засади формування компетентності як інтегративної характеристики, що поєднує систему знань, умінь, навичок, дослідницький досвід і соціально-комунікативні якості. Обґрунтовано роль фізики як базової дисципліни у структурі STEM-освіти, що забезпечує формування наукового мислення, здатності до моделювання та розв'язання прикладних задач.

Проаналізовано особливості формування STEM-компетентностей з фізики в Україні, де домінує фундаментальна теоретична підготовка з поступовою інтеграцією міждисциплінарних підходів, а також у США, де освітній процес характеризується практико-орієнтованістю, широким використанням дослідницького та проєктного навчання, інтеграцією цифрових технологій і чіткою орієнтацією на результати навчання.

У роботі узагальнено структуру основних STEM-компетентностей з фізики, що включає фундаментальні знання, аналітичні, дослідницькі, обчислювальні компетентності, а також м'які навички і професійну орієнтацію. Представлено модель формування цих компетентностей, яка охоплює цільовий, змістовий, методичний, технологічний, діяльнісний, оцінювальний і результативний компоненти, та здійснено їх порівняльний аналіз у контексті двох освітніх систем.

Окрему увагу приділено аналізу нормативно-правового забезпечення STEM-освіти, включаючи національні та міжнародні рамкові документи, що регламентують формування компетентностей. Виявлено спільні тенденції розвитку STEM-освіти, зокрема орієнтацію на міждисциплінарність, цифровізацію та компетентнісний підхід, а також визначено відмінності, пов'язані зі ступенем практичної спрямованості, рівнем стандартизації та інтеграцією з ринком праці.

Результати дослідження засвідчують необхідність подальшого вдосконалення процесу формування предметної компетентності студентів з фізики в Україні шляхом посилення практичної складової навчання, інтеграції сучасних технологій та використання ефективних міжнародних практик.

Ключові слова: STEM-освіта, вища освіта, заклад вищої освіти, університет, компетентність з фізики, STEM-компетентності, Україна, США.

Batyuk L. V., Masych V. V. The formation of students' subject competence in physics in the conditions of STEM education in Ukraine and USA

The article provides a comparative analysis of the formation of subject competence in physics of the students in the conditions of receiving STEM education in higher education institutions of Ukraine and USA. The theoretical principles of the formation of competence as an integrative characteristic that combines a system of knowledge, skills, abilities, research experience and socio-communicative qualities are revealed. The role of physics as a basic discipline in the structure of STEM education is substantiated, which ensures the formation of scientific thinking, the ability to model and solve applied problems.

The features of the formation of STEM competences in physics in Ukraine, where fundamental theoretical training dominates with the gradual integration of interdisciplinary approaches, as well as in the USA, where the educational process is characterized by practice-orienteers, extensive use of research and project-based learning, integration of digital technologies and a clear focus on learning outcomes, are analyzed.

The paper summarizes the structure of the main STEM competences in physics, which includes fundamental knowledge, analytical, research, computational competencies, as well as soft skills and professional orientation. A model for the formation of these competencies is presented, which includes target, content, methodological, technological, activity, evaluation and outcome components, and their comparative analysis is carried out in the context of two educational systems.

Special attention is paid to the analysis of the regulatory and legal support of STEM education, including national and international framework documents regulating the formation of competencies. Common trends in the development of STEM education are identified, in particular, the orientation towards interdisciplinarity, digitalization and a competency-based approach, and differences related to the degree of practical orientation, level of standardization and integration with the labor market are also identified.

The results of the study indicate the need for further improvement of the process of forming subject competence in physics of the students in Ukraine by strengthening the practical component of training, integrating modern technologies and using effective international practices.

Key words: STEM education, higher education, higher education institution, university, competence in physics, STEM competence, Ukraine, USA.

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