СВІТОВІ ТЕНДЕНЦІЇ ТА ВІТЧИЗНЯНІ ПЕРСПЕКТИВИ РОЗВИТКУ ВИЩОЇ ОСВІТИ

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Batyuk L. V.
Candidate of Biological Science, Associate Professor,
Associate Professor at the Department of Physics and Chemistry
H.S. Skovoroda Kharkiv National Pedagogical University
Kharkiv, Ukraine
E-mail: *l.batyuk@hnpu.edu.ua*
ORCID: *0000-0003-1863-0265*

INTEGRATION OF STEM APPROACH INTO STUDENTS' MATHEMATICAL TRAINING: EXPERIENCE OF UNIVERSITIES IN THE USA AND UKRAINE

Abstract

The paper examines the theoretical foundations of STEM education, identifies the role of mathematics as a component of STEM education, and outlines the features of implementing the STEM approach in higher education in the United States and Ukraine, taking into account national educational traditions. The comparative analysis was carried out according to the following criteria: the level of integration of the STEM approach into the mathematical training of students, the complexity of educational programs and courses, practical orientation, the use of project and research activities, the use of digital technologies and modern teaching methods. Particular attention is paid to the composition of basic and applied mathematical disciplines, the level of interdisciplinary integration, the flexibility of educational programs, and the forms of organizing the educational process. It was found that American programs are characterized by a high level of academic mobility, practical orientation, and extensive use of project activities, while Ukrainian educational programs provide thorough fundamental mathematical training. It has been established that courses focused on the application of mathematical methods in specific fields play a significant role in American universities, in particular numerical methods, mathematical modeling, data analysis, statistics, optimization, and computer mathematics. Such courses are often integrated with programming, engineering problems, and research projects, which contributes to the formation of students' practical competencies. A comparative analysis of undergraduate education at universities in the United States and Ukraine was conducted using the example of programs in the specialty «Applied Mathematics» and «Mathematics in Educational Institutions». This choice is due to the fact that «Applied Mathematics» is one of the key areas of STEM education in the United States, as it combines in-depth theoretical training with the practical application of mathematical methods in natural sciences, engineering, economics, information technologies, and pedagogy. The analysis of educational programs within these specialties allows for a comprehensive assessment of the level of integration of the STEM approach, the effectiveness of interdisciplinary connections, and the orientation of training specialists to solve real professional tasks. Based on the analysis, common and distinctive features of training specialists in mathematics in the context of STEM education were identified, and possible directions for adapting foreign experience to the conditions of the Ukrainian higher education system were outlined in order to improve its quality and competitiveness.

Key words: *STEM education, STEM mathematics, mathematics, higher education, educational programs, universities in the USA, Ukraine, comparative analysis.*

Introduction. In the current conditions of globalization, digitalization and rapid development of knowledge-intensive technologies, the role of STEM education as a key factor in training competitive specialists in the fields of science, technology, engineering and mathematics is growing [2; 8; 9]. A special place in the structure of STEM education belongs to mathematical training, since mathematics is the universal language of scientific knowledge, a tool for modeling, analyzing and predicting processes in various spheres of human activity.

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Applied mathematics as an educational specialty combines fundamental mathematical knowledge with practical methods of their application in computer science, engineering, economics, natural and social sciences. In this context, a comparative analysis of educational programs in applied mathematics in universities of different countries, in particular Ukraine and the United States of America, which have different traditions, approaches and models of organizing higher education, is of particular importance [13; 16; 17; 19; 1].

The US higher education system is characterized by the flexibility of curricula, wide possibilities of choosing disciplines, interdisciplinary integration and orientation on the practical application of mathematical knowledge within the STEM approach [3]. At the same time, Ukrainian higher education, in particular the H.S. Skovoroda Kharkiv National Pedagogical University, preserves strong traditions of fundamental mathematical training, which forms a solid theoretical basis for professional activity and further scientific development.

The relevance of this study is due to the need to understand the possibilities of adapting the best practices of American universities in the field of STEM mathematics to the Ukrainian educational space, taking into account national educational standards, pedagogical traditions and labor market needs. Comparison of the content, structure and focus of curricula allows us to identify common features and fundamental differences in the training of specialists, as well as outline the prospects for the modernization of mathematical education in Ukraine.

The aim of the work is a comparative analysis of the curricula and content of mathematics courses in educational institutions at US universities and H.S. Skovoroda Kharkiv National Pedagogical University in the context of STEM education. To achieve this goal, it is planned to analyze the list and content of basic and applied mathematical disciplines, determine the level of their practical orientation and interdisciplinary integration, and also assess the possibilities of using foreign experience in Ukrainian educational practice.

Research results. Mathematics occupies a central place in the structure of STEM education, as it acts as a universal tool for describing, analyzing and modeling processes in science and technology. It is mathematical methods that provide for the formalization of scientific knowledge, the construction of algorithms, data analysis and the prediction of research results.

In the context of STEM education, mathematics performs a number of key functions:

– methodological, as it forms logical and abstract thinking;

– instrumental, ensuring the solution of applied problems in physics, engineering, computer science and economics;

– integrative, combining different fields of knowledge within interdisciplinary projects.

STEM mathematics involves shifting the emphasis from the mechanical assimilation of formulas and algorithms to their meaningful use in real or close-to-real situations. Particular attention is paid to mathematical modeling, analysis of large data sets, numerical methods and the use of modern software tools.

The concept of «STEM mathematics» in modern scientific and pedagogical research is interpreted as a direction of mathematical education that integrates fundamental mathematical knowledge with practical and applied aspects of their use in STEM fields. Unlike classical academic mathematics, STEM mathematics is focused on results, practical feasibility and interdisciplinary interaction [4].

The characteristic features of STEM mathematics are:

– focus on solving applied and complex problems;

– use of project and problem-based learning;

– integration of mathematical disciplines with computer science, physics, engineering;

– active use of digital tools and mathematical packages.

STEM mathematics contributes to the formation of students' ability to see mathematical patterns in practical situations and use mathematical methods as a means of making informed decisions.

The competency-based approach is the methodological basis of STEM mathematics in higher education. Its essence lies in the formation of not only a system of knowledge, but also the ability to apply this knowledge in professional and life situations. Within STEM mathematics, mathematical, digital, research and engineering competences are key.

Mathematical competence in the STEM context includes the ability to mathematically think, model, analyze and interpret results. Digital competence involves the possession of software tools for calculations, visualization and data analysis. Research competence is formed through the implementation of projects, analysis of experimental data and substantiation of conclusions [5; 7; 10; 14].

Thus, the competency-based approach ensures the practical orientation of STEM mathematics and its compliance with the requirements of the modern labor market.

US universities have a flexible structure of study, where undergraduate students choose a specialization (major), but at the same time can take courses from other fields, including mathematical and STEM disciplines. This provides freedom to shape an individual educational path and combine subjects according to interests. American STEM programs are mostly integrated with practical laboratory, project work and interdisciplinary courses that prepare students for real-world engineering, science and technology tasks. Higher education is generally more focused on research and innovation – many universities have active research centers, grant support and close ties with industry.

The Ukrainian education system after the Bologna process switched to degrees (bachelor/master), but the curriculum is traditionally more standardized and disciplined, with fixed courses for specialties. STEM is gradually being introduced in Ukrainian universities, but is not always widely integrated into all programs; the emphasis is on fundamental study of disciplines, rather than on interdisciplinary projects or practical cases.

Standards and preparation for STEM (including mathematics) in the USA include:

– standardized SAT/ACT tests, which, in particular, contain mathematical sections that affect university admissions, but this is only part of the assessment;

– in universities, mathematics is a key component of STEM, but courses can be built according to the student's choice within the total number of credits;

– preparation for teaching mathematics and STEM in the USA has a deep pedagogical base and training for teachers that supports modern methods and technologies.

Unlike the USA in Ukraine:

– Ukrainian students often choose mathematics courses according to a more rigorous program, where there is little independent choice outside the specialty;

– the implementation of STEM education and the integration of mathematics with technology and engineering continues, but the laboratory infrastructure and student practice are not yet at the same level as in leading US universities.

– despite efforts, artificial intelligence and technology have not yet become a full part of everyday mathematics education, but are gradually being introduced (e.g. as learning support tools).

Despite a strong system, the US faces challenges with attribution of students in STEM disciplines (losing interest) and comfort levels for different groups of students. Ukraine is actively reforming STEM training, implementing international approaches, but a complete transformation requires time and resources. To improve the quality of education, especially in war and post-war times, the role of international cooperation (teacher visits, exchanges, partnership projects) is very important, which is reflected in a number of resolutions of the Government of our state on cooperation and exchange of experience [11; 12].

In the United States, mathematics courses in programs at top US universities, particularly in applied/higher mathematics and STEM, are not taught separately, but are integrated with practical cases and projects, with an emphasis on applications in technology, engineering, and data analysis.

For example, Harvard University (mathematics) [21; 27]. Math 55 is one of the most famous mathematics courses in the USA. A two-year course for freshmen in algebra, group theory, real and complex analysis – effectively covering most of university mathematics in 2 semesters. Includes:

1) Abstract algebra (groups, linear spaces);

2) Real and complex analysis;

3) Elements of topology and sometimes differential geometry in problems.

Such a course is often used as a fundamental start for future researchers in mathematics, physics or computer science.

Other standard mathematics courses at Harvard (and similar universities) include:

1) Analysis I–II (function theory and integration in generalized spaces);

2) Algebra I–II (theory of groups, rings, fields);

3) Topology and Differential Geometry.

These courses build the foundation for specializations in mathematics, statistics, data theory, and physics.

In contrast to Harvard University, Stanford University offers Introductory Math Courses [25], which consist of:

1) Math 51–53 – foundational courses for all STEM majors (calculus, linear algebra, discrete mathematics).

2) The program emphasizes the application of mathematics to physics, computer science, and economics.

US universities often have separate majors with a focus on modern applications of STEM mathematics: Applied Mathematics / Data Science / Statistics as separate bachelor's/master's programs at MIT, Stanford, UC-Berkeley, etc. [26]. These programs include mathematical analysis, numerical methods, statistics, data processing, and modeling, closely related to engineering, economics, and the IT sector. In Ukrainian universities, educational programs in mathematics and related areas usually include: Algebra and geometry, higher mathematics, mathematical analysis, linear algebra, differential equations, mathematical modeling, numerical methods, statistics, etc. Mathematics programs in Ukraine have a classical academic structure: several mandatory mathematical cycles in the first and second years and specialized subjects in the senior years. In Ukraine, traditional university mathematics with standard disciplines focused on fundamental knowledge (analytical mathematics, probability theory, mathematical modeling, etc.) is mainly studied (see Table 1).

Table 1

Mathematics education in higher education institutions at universities in the USA and Ukraine

Aspect	USA (Harvard, Stanford, etc.)	Ukraine (classical universities)
Course level	High, often proof-oriented and with elements of analysis/algebra at early stages (Math 55)	Basic, academically structured list of disciplines (analytic, linear alg., differential equations…)
Practical direction STEM	Often integrated with computer/applied problems (data, modeling)	Main emphasis on theory; practice is more often derived through separate modeling courses or IT applications
Focus on interdisciplinarity	Built into IT, engineering, data science programs	More often as a separate block (math + IT) in most universities
Flexibility of course choice	Higher (broad choice and individual trajectories)	Lower (rigid list of required courses)

In the US, mathematics is often a tool for practical STEM applications – statistics, optimization, data modeling, which is important for IT and R&D. Courses in the US can be of a higher level of complexity and depth (like Math 55 at Harvard), but also include more broadly applied skills. Ukrainian programs provide strong fundamental training, but sometimes they can lack modern integration with IT tools and project practices.

Let's break down specific courses from bachelor's programs in Applied Mathematics at US universities (Miami University, Old Dominion University) [22; 23] and make a comparative comparison with typical courses educational program «Mathematics in Educational Institutions» of the first (bachelor's) level of higher education, bachelor's degree, field of knowledge an Education in specialty A4.04 Secondary education (Mathematics) of the H.S. Skovoroda Kharkiv National Pedagogical University [6].

Miami University, often referred to as Miami of Ohio, is a public research university located in Oxford, Ohio, United States. It is one of the oldest public universities in the country, founded in 1809 [22]. It is the tenth-oldest public university in the United States. In the 2026 National University Rankings, the university is ranked 12th in the nation for undergraduate teaching quality. In fall 2024, the total undergraduate enrollment was 16 816. Miami University is a member of the University System of Ohio and is classified as a research-intensive university (R2) [15]. The university offers more than 120 undergraduate programs and more than 70 master's and doctoral programs.

Miami University, USA, has introduced Applied Mathematics B.S. for students. The main courses according to the university catalog are basic and applied [20].

Basic / mandatory:

1. Introduction to Linear Algebra (MTH 222) – linear algebra: vectors, matrices, systems of linear equations.
2. Calculus III (MTH 252) – multidimensional integral and differential, vectors, fields.
3. Differential Equations (MTH 347) – ordinary differential equations and their applications.
4. Real Analysis (MTH 441) – theory of real numbers and functions (rigorous analysis).
5. Probability / Probability & Stats (STA 401) – probability and data processing.

Applied / electives:

6. Applied Linear Algebra (MTH 433) – application of linear algebra in data processing, PCA, etc.
7. Numerical Analysis (MTH 453) – numerical methods for solving problems.
8. Introduction to Partial Differential Equations (MTH 455) – basic PDEs and their applications.
9. Optimization / Mathematical Modeling (MTH 432 / 435) – optimization or modeling of real problems.
10. Introduction to Nonlinear Dynamics (MTH/MME 495) – nonlinear dynamics.

The course structure allows for flexible specialization and combining mathematical courses with IT / data / engineering.

Old Dominion University (ODU) is a public research university in Norfolk, Virginia, USA. Founded in 1930 as the Norfolk Division of the College of William and Mary, it enrolled 23 494 students in 2023. The university offers 175 undergraduate and graduate programs and is divided into seven colleges and three schools. Its name derives from one of Virginia's nicknames, «Old Dominion», bestowed upon the state by King Charles II of England for its loyalty to the crown during the English Civil War. The Carnegie Classification of the University of Virginia places it at «R1: Doctoral Universities – Very High Research Activity».

Old Dominion University Applied Mathematics includes the following courses:

1. Calculus IV: Introductory Analysis (MATH 317) – real analysis with advanced features.
2. Applied Numerical Methods I (MATH 408) – numerical methods for ODE/PDE algorithms.
3. Applied Mathematics I: Biomathematics (MATH 420) – modeling problems in a bio-context (ODE, modeling).

At most US universities, the list of courses is divided into basic mathematical disciplines (calculus, algebra, differential equations) and applied / advanced disciplines (numerical methods, modeling, optimization).

According to the educational and professional program «Mathematics in Educational Institutions» in Ukrainian universities (in particular, in H.S. Skovoroda Kharkiv National Pedagogical University), the following Fundamental Mathematics courses can be distinguished:

– Mathematical analysis – classical analysis, integrals, series.
– Linear algebra and separately Analytical geometry – vectors, matrices, spaces.
– Mathematical logic – systems, applications.
– Probability theory and mathematical statistics - probability and data analysis.
– Discrete mathematics – logic, algorithms, graphs.
– Algebra and number theory – numerical algorithms for solving problems.
– Computer/practical courses:
– Fundamentals of computer science and programming – basics of writing programs for calculations.
– Practicum of solving construction problems – logic and optimization.
– Projective geometry and image methods – applied IT skills.
– WEB technologies, databases – IT tools and applications.

The educational program in Ukraine includes both classical mathematical disciplines and computer metrics and practices, but sometimes in a more structured and more academic context, with less selectivity and emphasis on interdisciplinary applications (see Table 2).

Table 2

Comparison of the undergraduate curricula of the educational program «Applied Mathematics» of the USA and the educational program «Mathematics in Educational Institutions» of the specialty A4.04 Secondary Education (Mathematics) of Ukraine

Course Topics	USA (Miami / ODU)	Ukraine (H.S. Skovoroda Kharkiv National Pedagogical University)
Basic Mathematics	Calculus (MTH 252) – Multivariate Analysis	Mathematical Analysis (classical course)
Linear Algebra	Introduction / Applied Linear Algebra	Linear Algebra /Analytical geometry
Differential Equations	Differential Equations (MTH 347)	Differential Equations
Statistics / Probability	Probability (STA 401)	Probability Theory and Mathematical Statistics
Numerical Methods	Numerical Analysis (MTH 453)	Algebra and number theory
Modeling / Applied Subjects	Optimization, Modeling Seminar, ODE/PDE Applications	Mathematical/Computer Modeling, IT Courses
Programming	Often elective (CS courses)	Programming (Python, C++) integrated

As shown in Table 2, in higher education institutions in the United States of America, the subjects of educational courses are clearly divided into basic mathematics and applied/computer disciplines, with the possibility of choosing specializations (optimization, modeling, statistics). There is flexibility of choice - students can choose courses in CS, data science, optimization, etc. Courses often include projects, modeling, software tool. The curriculum in Ukraine (H.S. Skovoroda Kharkiv National Pedagogical University) has a broad fundamental mathematical base (analysis, linear algebra, statistics, ODE, discrete mathematics). Computer courses and modeling are integrated into the program. Fewer elective or interdisciplinary courses compared to the US.

Conclusions. The study analyzed the theoretical and practical aspects of implementing the STEM approach in the mathematical training of students in higher education institutions in Ukraine and the United States of America using the example of educational programs in the specialty «Applied Mathematics» (USA) and «Secondary Education. Mathematics» (Ukraine). The analysis allowed us to draw a number of generalized conclusions. It was established that STEM education is a modern integrated educational model in which mathematics plays a system-forming role, providing a methodological basis for scientific research, engineering developments and digital technologies. STEM mathematics is focused on the practical application of knowledge, mathematical modeling and interdisciplinary integration. It was found that applied mathematics programs in US universities and at the S. Skovoroda Kharkiv National Pedagogical University have a common fundamental core, which includes courses in mathematical analysis, linear algebra, differential equations, probability theory and mathematical statistics. This indicates the universality of basic mathematical training regardless of the national educational model. Significant differences in the structure and implementation of educational programs have been identified. American universities are characterized by a high level of academic flexibility, a wide selection of applied and interdisciplinary courses, as well as the active use of project and research activities. In contrast, Ukrainian programs are characterized by a more rigid structure of curricula and the predominance of theoretical training. It has been proven that STEM-oriented programs in the United States have a pronounced practical orientation, which is implemented through capstone projects, teamwork, and the integration of mathematical disciplines with computer science and engineering. In the domestic higher education system, such elements are presented in a limited way and require further systematic implementation. The feasibility of using the positive experience of American universities to modernize Ukrainian educational programs in applied mathematics is substantiated, in particular by expanding the elective component, strengthening interdisciplinary integration, introducing project-based learning, and actively using digital tools in mathematical training. Thus, the results of the study confirm that the combination of thorough fundamental mathematical training inherent in Ukrainian higher education with the practically oriented STEM approach of US universities can be an effective way to improve the quality of training of specialists in applied mathematics and their competitiveness in the international labor market.

Prospects for further research are related to an in-depth study of practical mechanisms for implementing the STEM approach in the mathematical training of students of higher education institutions of Ukraine. An important direction is the analysis of the effectiveness of integrated STEM courses, interdisciplinary training modules and project-research activities in the process of training future specialists. Further scientific research can also be aimed at developing models for the modernization of educational programs taking into account the best practices of US universities and the needs of modern educational and digital environments.

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Батюк Л. В.
кандидат біологічних наук, доцент,
доцент кафедри фізики і хімії
Харківський національний педагогічний університет імені Г.С. Сковороди
Харків, Україна
E-mail: *l.batyuk@hnpu.edu.ua*
ORCID: *0000-0003-1863-0265*

ІНТЕГРАЦІЯ STEM-ПІДХОДУ У МАТЕМАТИЧНУ ПІДГОТОВКУ СТУДЕНТІВ: ДОСВІД УНІВЕРСИТЕТІВ США ТА УКРАЇНИ

Анотація

У роботі розглянуто теоретичні засади STEM-освіти, визначено роль математики як компонента STEM-освіти та окреслено особливості реалізації STEM-підходу у вищій школі США та України з урахуванням національних освітніх традицій. Порівняльний аналіз здійснено за такими критеріями: рівень інтеграції STEM-підходу у математичну підготовку студентів, комплексність освітніх програм та курсів, практична орієнтованість, використання проєктної та дослідницької діяльності, застосування цифрових технологій і сучасних методів навчання. Особливу увагу приділено складу базових і прикладних математичних дисциплін, рівню міждисциплінарної інтеграції, гнучкості освітніх програм та формам організації навчального процесу. Встановлено, що американські програми характеризуються високим рівнем академічної мобільності, практичною орієнтацією та широким використанням проєктної діяльності, тоді як українські освітні програми забезпечують ґрунтовну фундаментальну математичну підготовку. Встановлено, що в американських університетах значну роль відіграють курси, орієнтовані на застосування математичних методів у конкретних галузях, зокрема чисельні методи, математичне моделювання, аналіз даних, статистика, оптимізація та комп'ютерна математика. Такі курси часто інтегруються з програмуванням, інженерними задачами та дослідницькими проєктами, що сприяє формуванню практичних компетентностей студентів. Проведено порівняльний аналіз навчання бакалаврів в університетах США та України на прикладі програм зі спеціальності «Прикладна математика» та «Математика в закладах освіти». Такий вибір зумовлений тим, що «Прикладна математика» є одним із ключових напрямів STEM-освіти в США, оскільки поєднує глибоку теоретичну підготовку з практичним застосуванням математичних методів у природничих науках, інженерії, економіці, інформаційних технологіях та педагогіці. Аналіз освітніх програм у межах цих спеціальностей дає змогу комплексно оцінити рівень інтеграції STEM-підходу, ефективність міждисциплінарних зв'язків та спрямованість підготовки фахівців на розв'язання реальних професійних завдань. На основі проведеного аналізу визначено спільні та відмінні риси підготовки фахівців з математики в контексті STEM-освіти, а також окреслено можливі напрями адаптації зарубіжного досвіду до умов української системи вищої освіти з метою підвищення її якості та конкурентоспроможності.

Ключові слова: *STEM-освіта, STEM-математика, математика, вища освіта, освітні програми, університети, США, Україна, порівняльний аналіз.*

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