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INCORPORATING STEM APPROACHES INTO THE CURRICULUM OF QUANTITATIVE SUBJECTS IN UNIVERSITIES

INCORPORAÇÃO DE ABORDAGENS STEM NO CURRÍCULO DAS DISCIPLINAS QUANTITATIVAS NAS UNIVERSIDADES

INCORPORACIÓN DE ENFOQUES STEM EN EL CURRÍCULO DE LAS ASIGNATURAS CUANTITATIVAS EN LAS UNIVERSIDADES

Oleksandra ORDANOVSKA[1]
aleksordanovskaya@gmail.com
Oleksandra POTAPOVA[2]
remania2012@gmail.com
Halyna URUM[3]
Urum.HD@pdpu.edu.ua
Olga MARTYNYUK[4]
martynyuk.olga@gmail.com
Olena OLEFIR[5]
ms.l.olefir@gmail.com

[1] Doctor of Pedagogical Sciences, Professor, The State Institution "South Ukrainian National Pedagogical University named after K. D. Ushynsky", Odesa, Ukraine

[2] Candidate of Pedagogical Sciences, Associate Professor, University of Economics and Entrepreneurship, Khmelnytskyi, Ukraine

[3] Candidate of Technical Sciences, Associate Professor, The State Institution "South Ukrainian National Pedagogical University named after K. D. Ushynsky", Odesa, Ukraine

[4] PhD in Physical and Mathematical Sciences, Associate Professor, The State Institution "South Ukrainian National Pedagogical University named after K. D. Ushynsky", Odesa, Ukraine

[5] Candidate of Physical and Mathematical Sciences, Docent, Associate Professor, The State Institution "South Ukrainian National Pedagogical University named after K. D. Ushynsky", Odesa, Ukraine

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ABSTRACT: The article analyzes the application of the STEM approach in higher education, particularly in mathematics-related subjects. It highlights benefits such as increased student motivation, improved academic performance, and more positive attitudes toward learning. Based on a review of recent scientific literature from platforms like Scopus and Google Scholar, the study also identifies practical implementation challenges. It concludes that STEM education is essential for preparing professionals to face current and future challenges, fostering innovative solutions and contributing to cultural, social, and economic development.

KEYWORDS: STEM education. STEM technologies. Higher education. Higher education institutions. Mathematical disciplines.

RESUMO: *O artigo analisa a aplicação da abordagem STEM no ensino superior, especialmente em disciplinas matemáticas. Destaca os benefícios da metodologia, como aumento da motivação estudantil, melhoria no desempenho acadêmico e atitudes mais positivas diante das disciplinas. Utilizando revisão da literatura científica em bases como Scopus e Google Scholar, o estudo identifica também limitações na implementação prática da abordagem, apesar de seu potencial pedagógico. Conclui que a educação STEM é essencial para formar profissionais preparados para desafios atuais e futuros, promovendo soluções inovadoras e contribuindo para o desenvolvimento cultural, social e econômico.*

PALAVRAS-CHAVE: *Educação STEM. Tecnologias STEM. Ensino superior. Instituições de ensino superior. Disciplinas matemáticas.*

RESUMEN: *El artículo analiza la aplicación del enfoque STEM en la educación superior, especialmente en asignaturas relacionadas con las matemáticas. Destaca beneficios como el aumento de la motivación estudiantil, la mejora del rendimiento académico y una actitud más positiva hacia el aprendizaje. Basado en una revisión de la literatura científica reciente de plataformas como Scopus y Google Scholar, el estudio también identifica desafíos en su implementación práctica. Se concluye que la educación STEM es esencial para preparar profesionales capaces de enfrentar desafíos actuales y futuros, promoviendo soluciones innovadoras y contribuyendo al desarrollo cultural, social y económico.*

PALABRAS CLAVE: *Educación STEM. Tecnologías STEM. Educación superior. Instituciones de educación superior. Disciplinas matemáticas.*

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INTRODUCTION

In today's world, where technologies are rapidly developing, and the amount of information is growing exponentially rather than arithmetically, the emphasis in education needs to be shifted from simple mechanical memorisation of information to passing various tests to develop key competences that would allow the future use of the knowledge and skills gained in practice. A "competence" is a combination of personal qualities (values, abilities, knowledge, skills) that are determined by the experience of previous activities in a particular socially and personally significant area. Thus, according to data from Domo, which estimates minute-by-minute activity on the Internet, the volume of digital information in 2022 increased 47 times compared to 2010 and continues to grow (Domo, 2022). Modern education should promote the development of hard skills (specific to a particular profession) and soft skills (communication and interpersonal skills) to create competent human resources to compete internationally. In addition, the modern trend in education is lifelong learning, because, as already noted earlier, the speed of information dissemination and its volume make previously acquired knowledge and skills insufficient, which requires a person to compensate for their lack with constant self-education and self-improvement. Therefore, in education, there has been a transition from simple "transfer of knowledge" to mastering learning skills, selecting the necessary information, analyzing it, and systematizing it, that is, "learning to learn."

Mathematics as a science, which originally arose as one of the directions of searching for truth in the field of spatial relations (geometry) and calculations (arithmetic), has long gone beyond this understanding. After all, mathematics surrounds us in all spheres of life: everyday life, profession, art, and recreation.

The study of mathematics and mathematical disciplines in our time is an obligatory component of successful learning. And it is not about complex equations, fractions, trigonometry, etc., but about the development of universal memory skills, logical thinking, creativity, the ability to analyze, generalize, etc.

Recently, a STEM-oriented approach to education has become increasingly important in the development of education, especially in the natural sciences and mathematics, which provides students with a comprehensive, interdisciplinary, practical and creative learning experience that helps them to overcome the challenges of the 21st century and be better prepared for the rapidly changing technologies that fill the daily life of society.

However, teaching mathematical disciplines in higher education institutions is associated with a number of shortcomings, such as the formality of knowledge, a lack of links with other special subjects, a prescription in learning the material, poor mastery of new computer technologies, and a lack of practice. That is why the assessment of STEM education implementation to overcome these problems is relevant.

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Literature Review

The history of STEM education goes back further than you might think. It began in the United States of America with the Morrill Act of 1862, which established colleges across the country to provide land for the development of agricultural science. Later, the law was expanded to cover agriculture, engineering, and other industries, moving beyond education into the workplace and workforce training. The Second World War brought unprecedented progress due to military, business, and academic cooperation. This period brought innovations such as synthetic rubber, improved transport, and atomic weapons.

The acronym STEM is used to combine academic disciplines such as S-science, T-technology, E-engineering, and M-mathematics. It is usually defined as an approach to the educational process in which knowledge is acquired through the visualization of scientific phenomena, which makes it easier to grasp knowledge and understand how various processes occur (Marchenko, 2022).

Today, the STEM world is more than just a subset of academic disciplines—it is a means of shaping the thinking of students and professionals in a way that has a significant impact in the real world to understand natural phenomena better, use them in various fields of science and technology, develop technologies and implement them in the everyday life of society (Harrington, 2024).

The study aims to assess the implementation of STEM education in the teaching of mathematical disciplines in higher education institutions and the limitations and problems of such implementation.

Research methods

Using theoretical methods, we analysed the current scientific and methodological literature on the use of the STEM approach in teaching mathematics: the method of analysis identified the main aspects of STEM education, and the methods of synthesis, generalisation and systematisation were used to determine the main characteristics, advantages and limitations of such training, and the method of deduction was used to study the features of the integration of STEM education in higher education institutions. The leading search used the EuroPub, Google Scholar, Scopus, ResearchBib databases, and the business social network LinkedIn. The main emphasis and characteristics of the STEM approach to education and its advantages, disadvantages, and limitations in implementation were identified.

Particular attention is paid to the mathematical component of integrated STEM education and the integration of STEM into the educational process of teaching mathematical disciplines in higher education institutions.

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RESEARCH RESULTS AND DISCUSSION

Features of STEM education

Governments worldwide promote the STEM approach to education to increase student interest and achievement in science, technology, engineering, and mathematics and prepare STEM-qualified workers for 21st-century careers. In addition, STEM education is promoted to solve social and economic problems and create scientifically, mathematically, and technologically literate citizens. Leaders in many countries, governments, and business groups are making joint efforts to incorporate STEM into school curricula, encourage young people to participate in such learning, and promote STEM careers (Goos, Carreira, & Namukasa, 2023).

The National Education Association of the United States of America, through the collaboration of educators, education experts, and business leaders, developed the 21st Century Learning Framework to define the set of skills needed for success in work, life, and society. Initially, the framework consisted of 18 skills, which were later refined into four learning and innovation skills called "4Cs": critical thinking, communication, collaboration, and creativity, which have specific links to STEM education (Kennedy & Odell, 2024; Battelle for Kids, 2019; Akpan & Kennedy, 2020):

- Critical thinking and decision making: Students identify and analyse complex problems, break them down into manageable parts, and develop innovative solutions through problem-solving;
- Collaboration and communication: Through various project-based learning options, students work in teams to solve real-world problems. This collaborative approach fosters strong communication skills, helps students learn to work effectively with others, and promotes an appreciation of diverse perspectives;
- Creativity and innovation: STEM fields naturally foster a culture of creativity as students develop new technologies, conduct experiments or invent new solutions.

Integrated STEM education means treating two or more subjects not as separate and specialised subjects but as interrelated. For example, mathematical subjects (algebra, analytic geometry, and calculus) can be applied to specific physics problems such as acceleration and rotational motion. At the same time, biological knowledge of how air circulates inside a thermos has profound applications in engineering and architecture (How to integrate STEM education in Schools, n.d.).

STEM education models

In 2018, Hobbs et al. noted in the practice of Australian schools 5 different models of STEM education implementation, which differ in the degree and type of integration of individual disciplines, ranging from a complete lack of connection (represented as S-T-E-M) to full integration of all four disciplines (represented as STEM), as well as the presence of intermediate forms that have some similarities with multidisciplinary and interdisciplinary connections, described by Vasquez et al. in 2013. Table 1 describes these models.

Table 1. Models of STEM education implementation in Australian schools

Models of STEM education integration	Model description
S-T-E-M	Each discipline is studied separately.
SteM	All four disciplines are studied, but with an emphasis on one or two of them (in this example, S and M).
E / | \ S T M	One discipline is integrated into the other three, which are studied separately.
STEM	All disciplines are integrated into a subject taught by one teacher.
T / E / \ S M	The STEM curriculum is distributed among individual subjects so that each teacher teaches a subject-specific component of the combined unit.

Source: Hobbs, Clark and Plant, 2018.

Although these STEM models and approaches were described for school education, they are also relevant in higher education, as the principles, emphasis, and advantages of this educational approach are essentially unchanged and aimed at high-quality training of employees and professionals in various industries.

STEM education is for those with good aptitude and interest in science and those who want to explore intellectually complex processes. Not all students in a STEM programme will become scientists, inventors, engineers, or mathematicians, but they will be better prepared to solve real-world problems in any chosen field. STEM education emphasises applying knowledge, as the practical approach is crucial. Projects can include anything from computer coding and developing simple software applications to building structures, designing circuits, and assembling mechanical devices, such as robots. Many of these projects require collaborative efforts that help students understand the value of cooperation and teamwork (How STEM education improves student learning, n.d.).

Implementing STEM education takes time and a systematic approach. It is impossible to quickly change the established approach to teaching students of any level, especially teaching,

which requires not only material, technical, and methodological support but also teachers' professional skills. Training in this area should begin in primary school, where it is necessary to encourage curiosity, motivate the creation of simple devices and structures, conduct independent research, and support interest in learning and the search for knowledge.

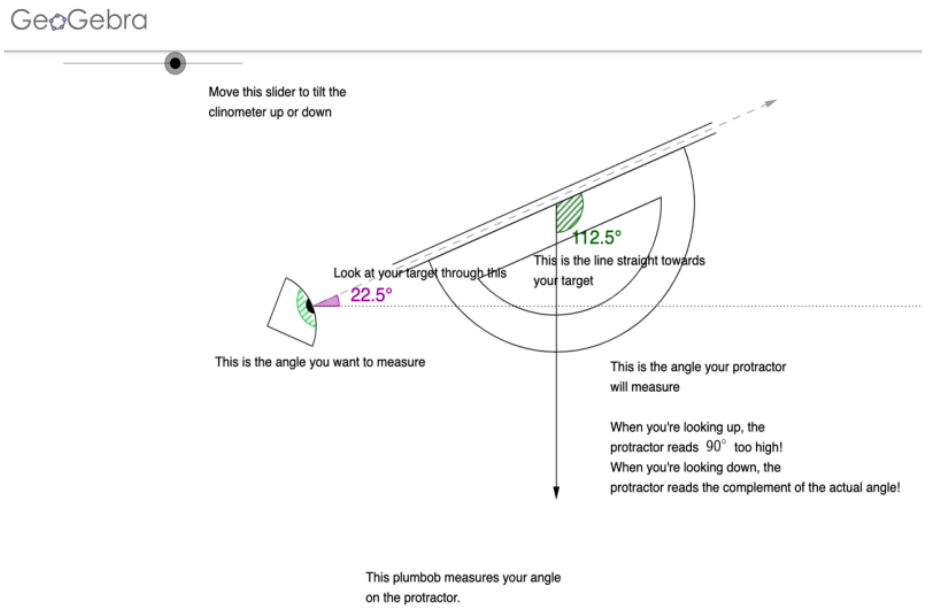
In secondary school, students should develop a strong interest in the natural and mathematical sciences. This will help them master the practical skills necessary for a thorough understanding of nature, ecology, life, and humans' place in the technosphere. Involving students in research and invention at this stage will increase the percentage of future talented scientists, engineers, and innovators.

In high school, a conscious choice of specialised studies and in-depth training in STEM disciplines should be promoted through awareness of the physical, scientific, technological, and technical picture of the world and mastery of the scientific methodology necessary to understand the development, functioning, and essence of global economic systems (Polikhun et al., 2019).

Features of studying mathematical disciplines using STEM

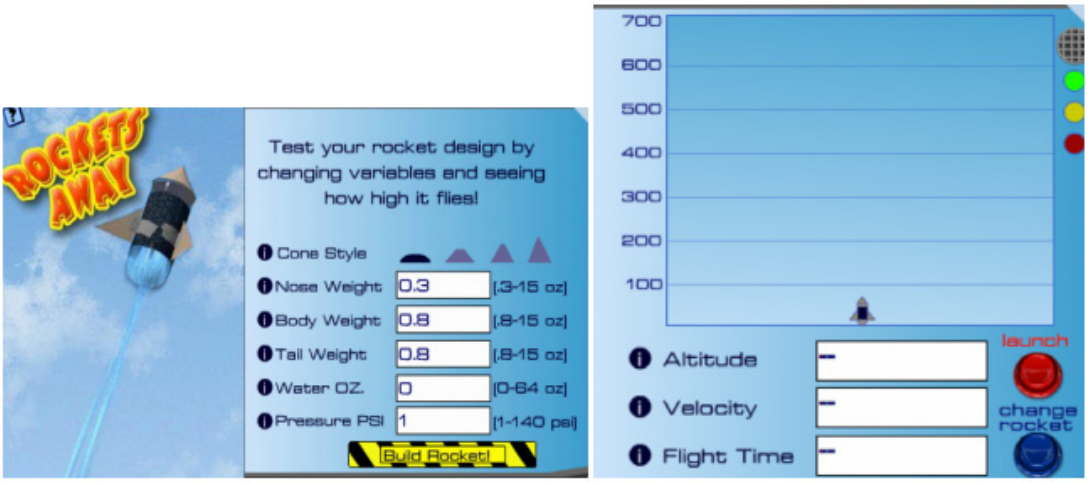
The study by Stohlmann (2020) is also relevant for higher education, given the content of student training programmes in mathematical disciplines. As an implementation of STEM through engineering design, modelling activities are most often used, which are student-centred, open-ended team-based, with realistic tasks that help students solve complex problems. Modelling activities allow students to see that most engineering problems do not have a single correct solution and emphasise the creative component of engineering. Examples of modelling activities for integrating mathematics into STEM include learning how a clinometer works in the GeoGebra application (Figure 1), launching a rocket in the Rocket simulator (Figure 2), designing and testing a catapult, calculating the angle of the ramp on the table and the distance from it to the cup on the floor so that the ball launched along the ramp hits the cup (Figure 3).

Figure 1. GeoGebra clinometer



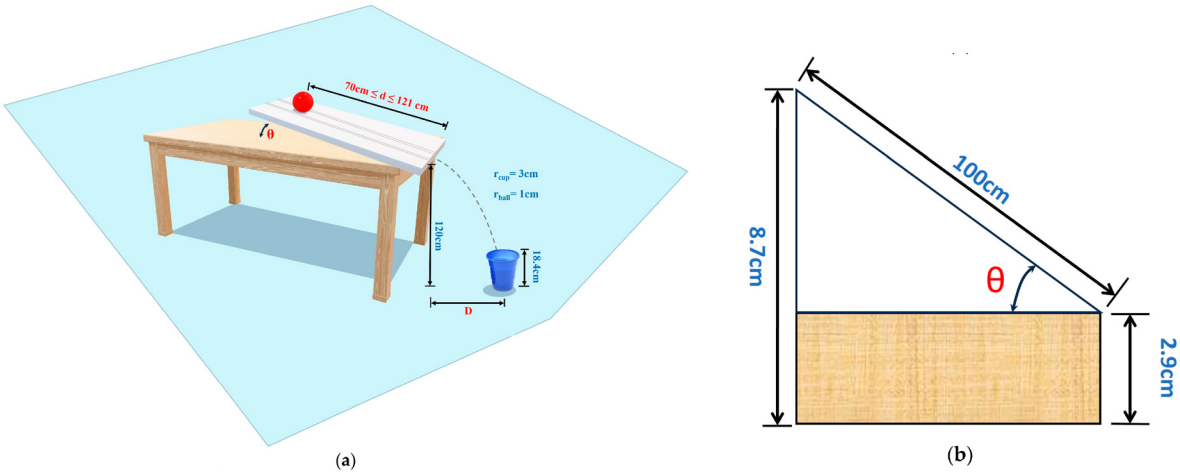
Source: Sdickson (2019).

Figure 2. Rocket simulator



Source: Ohio 4H (2017).

Figure 3. Drawing of the situation with measurements in blue and unknowns in red: (a) realistic image and (b) triangle used to calculate the ramp angle

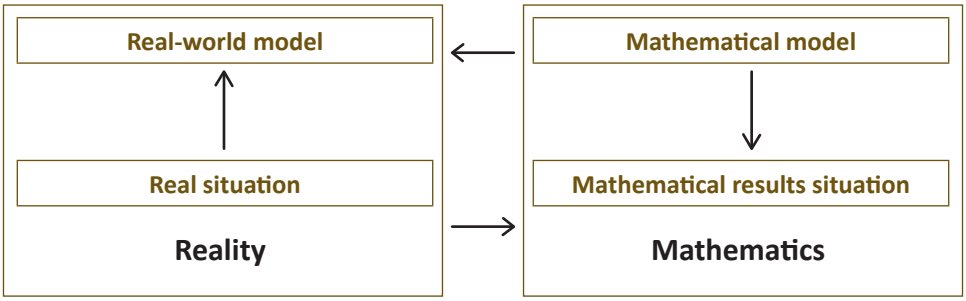


(a) (b)

Source: Dominguez et al. (2023).

Mathematical modelling attracts attention nationally and internationally due to advantages such as high student engagement and a better understanding of processes through numerous presentations and discussions. For example, students can calculate the estimated time of full use of oil reserves in the world at a given annual production rate, analyse the population of certain animal species and the factors that can affect it, and the expected population of a country at a given demographic rate. The mathematical modelling cycle of real-world problems consists of an actual situation, a real-world model, and a mathematical model, and results in two parallel sections (Figure 4). In the cycle, problem-solving is often perceived as a reference point for the situation (Tezer, 2020).

Figure 4. Mathematical modelling cycle



Source: Tezer (2020).

Technology-integrated mathematics has aroused considerable global interest, especially the use of a game component in teaching significantly increases students' motivation and interest in knowledge, making them more open to new information. Examples of such integration are programming and robotics (Siller et al., 2024). For example, Kim and Tjoe in

2019 cited the experience of using the Sphero SPRK+ robotic ball, the speed and trajectory of which were set using the SpheroEdu application (Kim & Tjoe, 2019). Students were asked to calculate the distance the ball could travel in a certain period along a particular trajectory and choose the trajectory and time of movement so that the ball covered a certain distance and stopped at a given point.

Limitations and obstacles to successful STEM education

The teacher is probably the most important factor in the effective implementation of integrated STEM education, as they should not just explain the topic of the lesson but "guide" the student along the path of learning about certain natural, technical or physical phenomena, explain the possibilities of using the potential of the technology being studied for personal and social benefit, help in the formation and consolidation of hard (professional) and soft (communication) skills, stimulate creativity and creativity. Teachers have faced difficulties shifting to learner-centred pedagogical approaches, implementing an integrated STEM curriculum in existing discipline-specific curricula, discussing structural barriers, and assessing student (Sevimli & Ünal, 2022).

In their study conducted in maritime educational institutions in Croatia, Latvia, Estonia and Poland in 2021, Gudelj A. et al. (2021) identified the need to modernise mathematics teaching methods, namely, linking theory to real-life problem-solving, more expansive use of modern IT methods and increased student engagement, which can be addressed through the implementation of STEM education.

Thus, despite the benefits of STEM education for training specialists in the modern world, its widespread implementation has significant limitations and challenges. Clear and consistent steps are needed to gradually introduce this approach into the educational process, for example: organising STEM courses according to academic levels and industries, providing teachers and students with access to the necessary equipment and services in simulation centres or research laboratories, strengthening ties between higher education institutions and enterprises in various industries, promoting STEM professions in society.

FINAL CONSIDERATIONS

Thus, STEM education is a modern, motivating, and comprehensive strategy for organising the educational process. It allows students to improve their knowledge and, most importantly, to use it in practice.

The main goal of integrating STEM education is to provide students with the opportunity to participate in solving real-world problems through hands-on experimentation, research,

design, and modelling. STEM education has the greatest impact when students can analyse data, draw conclusions based on evidence, and consider alternative opinions and points of view.

Studying mathematical disciplines using the STEM approach helps increase students' motivation to learn, better concentrate their attention on the subject, and improve their academic performance and attitude toward the classroom. Solving real-life problems in the present and future with the help of STEM will play an important role in providing innovative and creative perspectives on the cultural and economic development of countries.

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