STEM Training in Vocational Education: an Innovative Approach to Preparing Staff for the Economy of the Future

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Abstract

The paper examines the implementation of STEM education in vocational training, with a focus on the activities of the STEM center at the Vocational High School of Mechatronics and Electrical Engineering in the city of Pleven. The integration of interdisciplinary approaches in the fields of chemistry and environmental protection, power supply, information technologies and embedded systems provides opportunities for developing competencies related to the dual digital and green transition. The study focuses on innovative teaching methods, such as project-based learning, the use of microprocessor systems, 2D and 3D modeling and object-oriented programming, which allow the presentation of both real and virtual environments. Special attention is paid to the role of STEM education in preparing adaptive and competitive specialists for the needs of a climate-neutral and digital Europe. The challenges faced by teachers and institutions in implementing the STEM concept are also discussed. Emphasizes that STEM education in vocational schools is a key factor for the sustainable development of a modern, innovative and technological economy.

Keywords: *STEM Education; Vocational Training; Green Transition; Digital Transformation; Project-based Learning.*

STEM обучение в професионалното образование: иновативен подход към подготовката на кадри за икономиката на бъдещето

Introduction

Today, in the context of accelerated digitalization and the pursuit of climate neutrality, education is faced with the need to train a new type of specialists. Vocational high schools play a strategic role in this transformation, as they provide a direct link between school and industry. The introduction of STEM education in vocational education creates the conditions for integrating knowledge, skills, and competencies from different disciplines, oriented towards their practical application.

The Vocational High School of Mechanical and Electrical Engineering in Pleven has developed an innovative STEM center, whose activities will focus on the following subjects: Chemistry and Environmental Protection, Power Supply, Information Technology, and Embedded Systems. The selection of these disciplines is not accidental—they are directly related to the challenges of the dual transition: digital and green, as well as the need for accelerated transition to the new economy. The selection of these disciplines is not accidental—they are directly related to the challenges of the dual transition: digital and green,

as well as the need for an accelerated transition to an economy based on sustainable development and digital solutions.

EXPOSITION

1. The role of STEM education in vocational education.

The STEM approach in vocational schools combines theory and practice, focusing on the acquisition of key competences: critical thinking, digital literacy, knowledge of sustainable development, and teamwork skills [1], [2], [3]. It:

- builds and develops technical literacy, productivity, social skills, flexibility, and initiative on the part of students [4], [5];
- increases high school students' motivation to learn and the practical application of the knowledge and skills they have acquired [6], [7];
- improves teamwork skills and communication skills [3], [5];
- builds a unified understanding in students' minds of the interrelationship between school subjects and knowledge of new technologies [1], [2];
- develops cooperation between teachers of different subjects and between teachers and students [3], [8].
- helps to involve parents in the school's cause [7].

STEM education is beneficial for both students and society. It:

- supports the development of critical thinking, logical thinking, and analytical skills that can be used to solve real-world problems. It prepares students for future jobs [2], [3];
- develops skills that are essential for future jobs in high-tech industries such as information technology, engineering, biotechnology, and others [1], [6];
- encourages innovation and creative thinking, which lead to new ideas and products [2], [9];
- increases career opportunities - students who receive STEM education have greater career opportunities and better financial rewards compared to those who have not undergone such training [7];
- prepares learners for civic participation by encouraging them to become active citizens, helping them understand and make sense of the science and technology behind complex global issues such as climate change and healthcare [9], [10];
- It eliminates inequalities between different population groups and encourages young people to pursue careers in high-tech industries, regardless of their gender, social status, or ethnic origin [5], [9].

The STEM approach in vocational education is an integrated educational framework that combines science, technology, engineering, and mathematics with a practical focus. In vocational high schools, STEM education is implemented as a means of building key competencies needed for the modern labor market: critical and analytical thinking, digital and technological literacy, real-world problem-solving skills, teamwork, and adaptability [2], [3].

At PGMET – Pleven, STEM education is purposefully applied in the training of students in the fields of Power Supply, Electrical Equipment, Information Technology, and Natural Sciences [10], [11]. During the 2024/2025 academic year, 95 students from grades IX to XI, divided into 6 classes, are included in STEM activities.

Distribution of participants in STEM education by grade

Table 1.

Indicator	Number of students
Total number of participants	95

Table 2.

Indicator	Number of students
9th grade	32
10th grade	37
11th grade	26

Analysis: The data show relatively even participation of students from 9th to 11th grade, which allows for objective monitoring of the effect of STEM education at different stages of vocational training. This creates conditions for comparability of results and sustainability of conclusions.

The results of an internal school study (questionnaire method and pedagogical observation) show that STEM education:

- increases learning motivation – 82% of students report increased interest in school subjects;
- improves teamwork skills – 76% demonstrate better communication and coordination in project work;
- develops technical and digital literacy – an average increase of 23% in the results of incoming and outgoing diagnostic tests has been reported;
- forms an integral understanding of interdisciplinary connections, with 69% of students stating that they better understand the practical application of theoretical knowledge.

Table 3.

Competence	Improvement (%)
Digital literacy	21
Teamwork	18
Problem solving	24
Critical thinking	20
Learning motivation	28

Analysis:

The most significant growth was reported in learning motivation **(28%)**, confirming the strong motivational effect of project-based STEM education. Improvements in problem solving skills **(24%)** and digital literacy **(21%)** demonstrate the effectiveness of integrating theory and practice.

Despite the positive effects reported, challenges remain related to:

- shortage of qualified teachers and lack of educational materials - many countries lack sufficient qualified teachers to teach STEM subjects, as well as the necessary resources and educational materials for these subjects;

- insufficient motivation and interest on the part of students - despite the importance of STEM education, some students may find it boring or too difficult, which can reduce their interest and motivation to study it;
- Prejudices and stereotypes - there are still prejudices and stereotypes in society that prevent girls and women from pursuing STEM education and careers.
- Inequality in access - some students have fewer opportunities to access STEM education due to financial or geographical reasons. This can lead to inequality in students' learning and career development.
- Shortcomings in education - Given the pace of technological and scientific development, some teaching materials may be outdated or unsuitable for the contemporary needs of students. This can lead to insufficient preparation of students and limited success in their future careers.

STEM education has been developing in Bulgaria in recent years, but more investment and support are still needed to achieve a more advanced level of development in this area.

2. Integrated school subjects and their connection to the dual transition [10], [11].

Table 4.

School subject	Main focus	Connection to the dual transition
Chemistry and environmental protection	Research into environmental factors, analysis	Green transition – climate neutrality
Electricity supply	RES, green energy, efficient energy systems	Green transition – renewable energy
Information technology	Simulations, modeling, databases	Digital transition – digital solutions
Embedded systems	Microprocessors, automation, IoT	Digital transition – smart technologies

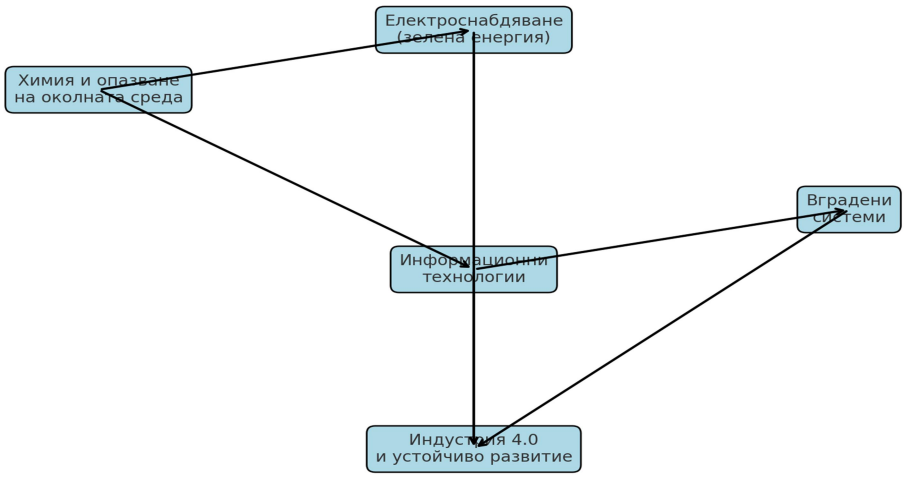

Fig. 1. Schematic model of STEM discipline integration

3. Innovative methods and practices [2], [3], [8]

- Project-based learning
- 2D and 3D modeling
- Object-oriented programming
- Integration of digital laboratories

Project-based and interdisciplinary lessons in a STEM environment on robotics and cyber-physical systems, green technologies, natural sciences, and digital skills using ICT tools and in laboratory conditions [1], [7].

The main advantage of STEM education is the integration of different educational subjects into the learning process, which will help students more easily understand the connections between the subjects they study at school. It will encourage students to discover their strengths, learn to work in a team, and understand that problem solving depends on them. It will prepare them for successful future careers in various fields of life by developing their logical thinking, problem-solving skills, digital literacy, and emotional intelligence.

Learning in a STEM environment will help young people experiment in a safe school environment. The STEM center will provide an opportunity to acquire basic knowledge, skills, and attitudes in the subjects of natural sciences, programming, power supply, and electrical equipment, with an emphasis on designing and building projects in electronic and physical environments. New digital competences will be developed in students, which will be applied in various subject areas. Opportunities will be provided to acquire basic skills in: working with digital platforms on algorithms, data structures and artificial intelligence, management of renewable energy sources, etc. Practical study of flora and fauna samples. Mastering basic knowledge, skills, and attitudes related to the use of ICT as a means of building students' digital competences, planning, designing, and building interdisciplinary connections.

In order to increase the effectiveness of the STEM center, digital work is planned for subjects in the natural sciences/chemistry group, combining project-based lessons in electronics, robotics, and others.

This will increase the professional competence of teachers teaching the relevant subjects, who, together with the methodological parameters set, will have to accumulate knowledge and skills in the field of digital technologies, coordinate their work with national and supranational institutions such as PARABulgaria, BAS, regional libraries, NIMH, and others. The training courses planned for teaching staff under the STEM project are linked both to the implementation of the general objectives and tasks set out in the school strategy and to the achievement of DOS in the teaching process.

In order to effectively realize the potential of the STEM center, it is necessary for the learning activities to be clearly structured and methodically thought out. In this way, project-based lessons and practical tasks will be introduced into the learning process, encouraging students to connect theory with real-world applications. The consistent structure of the lessons—from introduction to the topic, through practical activities and reflection, to assessment and integration with other disciplines—ensures not only the acquisition of knowledge but also the development of key skills for teamwork, critical thinking, and innovation. In this way, STEM education becomes a sustainable link between school, science, and real life.

Sample structure of a project-based lesson for STEM education.

Introduction to the topic

- Purpose: To familiarize students with the main topic and objectives of the lesson.

- Description: The teacher introduces the topic, explains why it is important, and how it relates to the real world. This may include discussing current events, issues, or demonstrations that spark students' interest.
- Example: In a lesson on climate change, the teacher might begin with a video or discussion about current environmental challenges.

Hands-on activity or lab exercise

- Purpose: To allow students to apply the theories they have learned through experiments and interactive tasks. It is important that students clearly see the connections between the objectives and the real world.
- Description: Students perform lab exercises, experiments, or practical tasks that help them understand and apply the concepts they have learned. They work individually or in teams.
- Example: In a chemistry lesson, students can perform an experiment to determine the pH (hydrogen index) of different solutions.

Reflection and discussion

- Purpose: To encourage students to reflect on what they have learned and discuss their discoveries and challenges.
- Description: Students discuss their observations and conclusions from practical activities and projects. This may include group discussions, written reflections, or presenting conclusions to the class.
- Example: After a chemistry experiment, students discuss the results and compare them with theoretical expectations.

Assessment and feedback

- Purpose: To assess student progress and provide feedback for improvement.
- Description: The teacher assesses students' understanding and performance of tasks through tests, project evaluations, or oral questions. Feedback is provided to help students improve their knowledge and skills.
- Example: After completing a project, students present their results and receive feedback from the teacher and their classmates.

Integration with other disciplines and the real world

- Purpose: To show how STEM knowledge connects to other disciplines and how it is applied in real life.
- Description: The lesson highlights the connections between STEM disciplines and other subject areas such as the arts, social sciences, or language arts. Students understand how STEM skills can be used to solve real-world problems.
- Example: In an ecology lesson, students explore how human activities affect the environment and discuss emerging solutions for sustainable development.

As part of the STEM activities, an empirical study was conducted among **95 students** using:

- questionnaires;
- incoming and outgoing tests;
- observation and analysis of student projects.

Measured competencies and results:

- digital skills – average increase of 21%;
- problem-solving skills – 78% of students demonstrated progress;
- motivation to learn – 84% reported a positive change;
- academic results – average increase in success by 0.45 points on a six-point scale.

Comparison of academic results before and after STEM training

Table 5.

Indicator	Before STEM	After STEM
Average success	4.12	4.57
Increase	–	+0.45

The data confirms that STEM education has a lasting positive effect on both academic results and the personal development of students [3], [6].

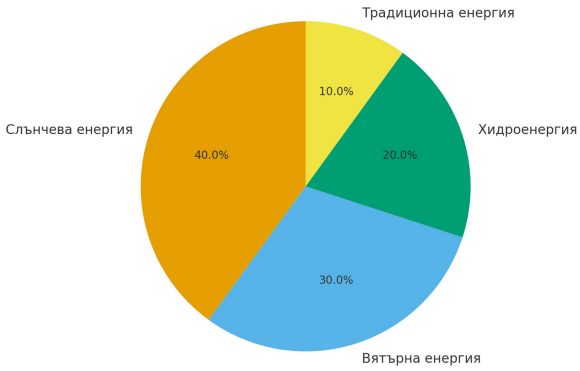

Fig. 2. Example of a STEM project – smart energy system (distribution of energy sources)

"Smart energy management system"

- Modeling in a **3D CAD environment**;
- Efficiency calculation

$$\eta = P_{out} / P_{in} \times 100\% \quad (1)$$

- Programming of embedded monitoring systems;
- Data visualization via IT platform.

The project demonstrates the practical application of STEM knowledge and the link between education, sustainable development, and real-world engineering solutions.

CONCLUSION

The structure of STEM lessons is designed to encourage active participation, knowledge integration, and practical applications. Through a combination of theoretical training, practical work, technological integration, and reflection, STEM lessons help students develop the skills and competencies necessary for success in the modern world [2], [9], [10].

The STEM center at the Professional High School of Mechanical and Electrical Engineering in Pleven is an example of how vocational education can be adapted to the requirements of the modern economy. By integrating natural sciences, engineering, technology, and mathematics, students develop the skills needed for the digital and green transition. The introduction of practice-oriented methods and partnerships with industry ensures that the trained specialists will be competitive and meet the needs of the future labor market [3], [11].

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