STEM ECOSYSTEMS: INTELLIGENT LEARNING ENVIRONMENTS THROUGH SENSORS, DATA, AND PROTOTYPING

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ABSTRACT: *Modern STEM education requires the creation of integrated learning ecosystems that connect science, technology, engineering, and mathematics within real-world, practical contexts. This article explores the concept of STEM ecosystems as intelligent learning environments based on the use of sensor technologies, data collection and analysis, and engineering prototyping. It presents a model of a learning environment in which students acquire knowledge by investigating and solving real-world problems, constructing research systems, working with microcontrollers and IoT devices, processing data, and developing prototypes.*

KEYWORDS: *Projectbased learning, IoT Education STEM education; Intelligent educational technologies*

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STEM ЕКОСИСТЕМИ: ИНТЕЛИГЕНТНИ СРЕДИ ЗА УЧЕНЕ ЧРЕЗ СЕНЗОРИ, ДАННИ И ПРОТОТИПИРАНЕ*

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АБСТРАКТ: *Съвременното STEM образование изисква създаването на интегрирани учебни екосистеми, които свързват науката, технологиите, инженерството и математиката в реални практически контексти. Настоящата статия разглежда концепцията за STEM екосистеми като интелигентни среди за учене, основани на използването на сензорни технологии, събиране и анализ на данни и инженерно прототипиране. Представен е модел на учебна среда, в която учениците придобиват знания чрез изследване и решаване на реални проблеми, конструиране на изследователски системи, работа с микроконтролери и IoT устройства, обработка на данни и разработване на прототипи.*

1 Introduction

Modern education faces the challenge of preparing students for a world in which technology, science, and innovation play a key role in building skills and competencies. In this context, STEM education plays a pivotal role, as it emphasizes not only the acquisition of knowledge but also the development of skills, mindsets, and abilities applicable in the real world. Within a STEM framework, students apply theoretical knowledge to solve real-world problems by utilizing engineering thinking, mathematical models, and technological skills.

These skills are essential for the personal and professional development of students in the dynamic world of the 21st century. A competency-based approach incorporates integrated, project-based learning, in which students simultaneously apply knowledge from various disciplines.

2 The nature of STEM ecosystems

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The nature of STEM ecosystems

Creating a STEM ecosystem establishes an educational environment where students and teachers collaborate to develop practical knowledge and skills, and to address challenges. The primary focus is on "project-based learning, in which knowledge from various disciplines is integrated to solve specific tasks" [1]. At the heart of the STEM ecosystem lies the student, who not only acquires theoretical knowledge but also applies it in real-world situations through experimentation, modeling, and the creation of functional prototypes [2].

These learning environments comprise a combination of educational resources, digital devices, sensors, and applications that collect, process, and visualize necessary information. Such environments facilitate team-based learning and interactivity, offering opportunities to carry out practical, real-world projects related to the natural sciences or outdoor education—aligning with Pavlova's [3] conceptualization of "the real world as a learning space."

A key feature of STEM ecosystems is the use of sensors. These enable the measurement and monitoring of various environmental parameters, such as temperature, humidity, water levels, light intensity, motion, air quality, smoke, and other physical quantities. The data obtained can be analyzed and utilized to conduct empirical research and develop engineering solutions. Examples of projects that can be implemented include "Green Garden," "Interactive Agriculture," and "Smart Irrigation System," among others.



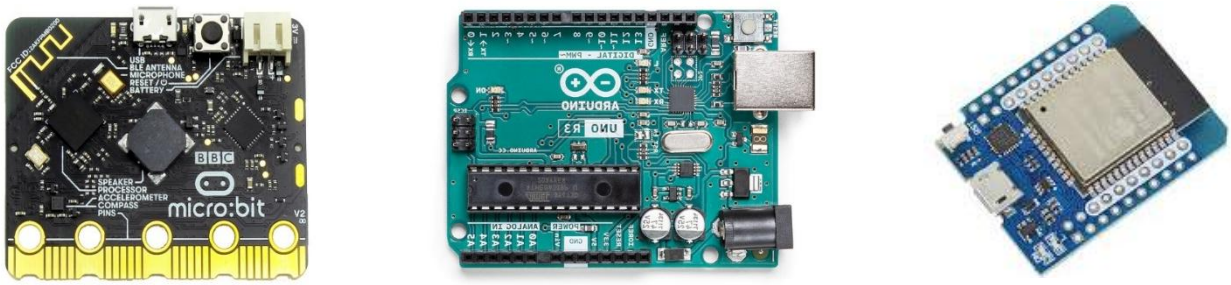
Figure 1 The Smart IoT Kit „Smart agriculture Kit" [5]

The Role of Sensors in Education

Creating a STEM ecosystem requires sensors and the right conditions to transform theoretical models into real-world solutions. For instance, students can build a smart greenhouse or a weather station that collects data on climatic and soil conditions in specific areas (such as the school grounds). By observing and analyzing the gathered information, they develop skills in data handling and processing, scientific and critical thinking, and the creation of statistical studies.

Knowledge gained in biology classes can be applied to monitor plant growth, soil moisture, light intensity, or air temperature; meanwhile, in physics classes, sensors can be used to measure acceleration, pressure, vibrations, or force.

In Bulgaria, several options are available for working with microcontrollers—such as Arduino, Micro:bit, Raspberry Pi, or ESP32—which enable the creation of custom autonomous systems with either automated or manual control. In this way, students can not only observe processes and changes but also actively participate in managing them.



Micro:bit Arduino ESP32

Figure 2 Microcontrollers boards [7], [8], [6]

Data as a Learning Tool

Access to data is one of the most valuable resources used for analyzing and managing models and processes. In STEM education, the use of data encourages students to collect, organize, visualize, and interpret information, which can then be applied to solving real-world, practical problems. By gathering information from sensors, students can utilize specialized software for analysis and visualization—creating graphs, tables, and statistical models. In doing so, they establish connections between mathematics, IT, and the natural sciences.

Data analysis also supports decision-making. For instance, in a plant-growing project, students can measure humidity, temperature, and light intensity, and subsequently propose practical measures for cultivating the plants.

Carrying out these projects requires long-term, goal-oriented planning and time for implementation. Many of the proposed projects take between two weeks and two months to complete. To this end, students could maintain a log or record data, which they can later analyze and compare with other projects. Furthermore, various types of solar-powered or energy-independent components can be incorporated into these STEM ecosystems, allowing the projects to integrate more naturally as real-world solutions to specific problems. To a large extent, these projects can be further developed and expanded if students have access to an enclosed natural area or an experimental field.

The Benefits of STEM Ecosystems

Working within these systems offers numerous educational advantages. They foster an inquiry-based approach to learning, stimulate creativity, and develop "initiative, critical thinking, inventiveness, independence, confidence, and other qualities valuable to the modern individual" [4].

Challenges and Prospects

Despite these significant advantages, implementing a STEM project as an ecosystem requires appropriate resources—such as physical infrastructure, experienced and qualified educators, and access to modern information technology. Furthermore, it is essential to promote

an interdisciplinary approach and foster collaboration among educational institutions, the business sector, and scientific organizations.

3 Conclusion

STEM ecosystems and smart learning environments represent a new stage in the development of education. Through the use of sensors, data analysis, and prototyping, students acquire practical skills that build upon traditional knowledge, preparing them for the dynamic demands of the modern world. These innovative approaches transform learning into an active, creative, and investigative process, aimed at fostering future engineers, scientists, entrepreneurs, and active citizens of the digital society.

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