STEM Education and Mechatronic Applications: Mechanisms, Devices, and Systems in the Development of Youth and Students

PhD student **Viorel NIȚICALĂ[1],** Researcher II / Lecturer **Iulian Sorin MUNTEANU[1,*],**
PhD student **Aurelian ȘTEFĂNESCU[1],** Prof. **Ana Maria MUNTEANU[2],**
PhD student **Daniel - Mircea POPESCU[1]**

[1] National University of Science and Technology POLITEHNICA Bucharest

[2] Nikola Tesla Technological High School

* iulian.munteanu0306@upb.ro

Abstract: *This article examines the essential role of STEM education in mechatronics, emphasizing its impact on developing youth and students. As nations recognize the necessity of preparing future generations for a technology-driven workforce, initiatives are being introduced to align higher education with Industry 4.0 demands. Through interdisciplinary projects and innovative methods, students gain vital skills in science, technology, engineering, and mathematics. The paper highlights successful educational programs and discusses the integration of STEM and mechatronic principles in curricula, promoting critical thinking and collaboration. It also reviews government initiatives in countries such as China, the United States, and Romania that aim to enhance STEM competencies, serving as catalysts for societal growth and innovation toward a prosperous future.*

Keywords: *STEM education, STEAM education, interdisciplinary projects, innovative learning, critical thinking, robotics, government initiatives, educational reform, global competitiveness, experiential learning*

1. Introduction. The importance and necessity of STEM education

STEM education (Science, Technology, Engineering, Mathematics) represents an integrated approach to four essential fields: science, technology, engineering, and mathematics. In an expanded version, STE(A)M includes the arts to encourage creativity and innovation. This interdisciplinary integration allows students to make connections between different fields and understand how they complement each other.

Through the STEM approach [1-4, 6, 7,14-17, 20], students can apply the knowledge they have gained in real-world contexts, directly impacting the development of critical thinking and problem-solving skills. Instead of isolating disciplines, STEM facilitates a holistic exploration of their interdependence. For example, understanding mathematical concepts becomes more accessible when applied in scientific experiments or engineering projects.

This practical approach not only strengthens theoretical knowledge but also stimulates creativity and innovation. Students learn how scientific principles influence new technological discoveries, how engineering drives innovation, and how mathematics supports these processes. This interdisciplinary perspective prepares them to effectively address complex challenges in industry and research.

A concrete example of STEM application in education is the use of mechatronic devices [5,18,19], such as mini weather stations, which allow students to collect and analyze real-time data. These educational projects not only improve technical skills but also contribute to the development of cognitive abilities such as problem-solving, statistical analysis, and error identification.

On the other hand, STEM education fosters innovation. Educational systems that do not promote a multidisciplinary approach can have a negative impact on the future of the industry and the ability to form innovative scientists and engineers. In this regard, a report from the University of Warwick highlights that the lack of multidisciplinary education "affects creativity in industry and the ability to produce technological leaders on a global scale" (STEM education).

2. STEM Education in universities and international competitions

In advanced economies, STEM education is an essential part of the university curriculum [1- 4, 6,7,9, 10-12,16,17, 20] and competitive educational programs. Universities in the United States, for example, are globally recognized for their research and innovations in STEM fields. Institutions such as MIT (Massachusetts Institute of Technology) and Stanford University place significant emphasis on interdisciplinary projects and industry collaboration. These universities offer specialized courses in robotics, artificial intelligence, and mechatronics, all integrated into their STEM programs.

• Prestigious university competitions

STEM-based academic competitions [8] are another method through which students in technical faculties can showcase their knowledge and skills. A remarkable example is the FIRST Robotics Competition (FRC), a global contest where student teams design and build robots to complete complex tasks. This competition not only provides valuable experience to participants but also offers the opportunity to innovate and work in teams.

In Germany, the Formula Student competition is one of the most prestigious platforms for engineering students. Teams from all over the world compete to design and build high-performance vehicles. This competition fosters collaboration between faculties and industry, contributing to innovation in mechatronics and intelligent transport systems.

• Public innovations and international recognition

Universities in industrialized countries often collaborate with the public and private sectors to support STEM innovations.

◘ A notable example is the DARPA Robotics Challenge, organized by the U.S. Department of Defense. This competition aims to develop robots capable of responding to emergency situations. Students, alongside researchers and technology companies, have the opportunity to innovate and contribute critical solutions within these contests.

◘ South Korea heavily invests in technology and STEM education, with its universities promoting robotics and programming innovation competitions. For instance, the World Robot Olympiad involves student teams competing in various disciplines, from robotics to artificial intelligence, frequently ranking high in global STEM competitions.

In countries with advanced economies, STEM education is crucial for developing the future skills of engineers and researchers. In addition to the United States and Germany, other nations such as Canada, Australia, New Zealand, and Japan have made significant strides in implementing STEM programs at universities and organizing specialized competitions.

◘ In Canada, top universities like the University of Toronto and the University of British Columbia are known for integrating STEM into research and education. These universities offer specialized programs in robotics, engineering, and mechatronics, providing students with opportunities to work on real-world projects in collaboration with industry. One example is the STEM Fellowship program, which promotes collaboration between students, researchers, and industry in data analysis and innovation projects in science and technology.

Canada also hosts competitions such as the Canadian Engineering Competition, where students demonstrate their technical problem-solving and innovation skills, gaining recognition nationally and internationally.

◘ In Australia, universities such as the University of Sydney and the University of Melbourne are recognized for advanced research in engineering and applied sciences. Competitions like RoboCup Junior Australia allow students to compete in robotics, applying STEM knowledge to build and program robots that perform various tasks.

◘ New Zealand has adopted a similar approach, with its universities actively promoting STEM research projects. An example is the Smart Ideas Challenge, organized by the University of Auckland, which encourages students to develop innovative solutions in green technology and robotics.

◘ Japan, known for its technological advancements, places significant emphasis on STEM education in technical and engineering faculties. Tokyo Institute of Technology and the University of Tokyo are two of the top universities offering extensive programs in mechatronic engineering and robotics. Competitions such as RoboCup Japan Open and the All Japan Robot-Sumo

Tournament allow students to develop their technical skills and innovate in areas such as artificial intelligence and robotics.
Moreover, Japan invests in public initiatives and STEM innovation contests, such as the Robot Development Project, which involves both researchers and students in the development of autonomous robots for industrial and social applications.

2.1. Educational projects based on mechatronics

A notable example of an educational mechatronics project, completed in Romania in 2024, is the Mini Weather Station (code MSM 001), developed as part of the MSSMM Master's Program «*Modeling and Simulation of Mobile Mechanical Systems*» at the Faculty of Industrial Engineering and Robotics (FIIR) - Bucharest. This project integrates essential elements from technology, engineering, and mathematics, using Arduino platforms and modules to build a functional device capable of collecting real-time meteorological data.
The Mini Weather Station (see Figure 1) was designed to be portable, easy to use, and capable of operating off-grid. The project is a successful example of STEM education application, allowing students to develop both technical and cognitive skills through the process of prototyping and practical testing.
The MSM 001 weather station includes Arduino-compatible modules, such as temperature, pressure, and humidity sensors, a real-time clock module, and a data storage module on microSD cards. These components enable students to monitor climate parameters in real-time and analyze the collected data, stored in CSV format, using specialized software such as MS Excel and KiCad. Additionally, the prototype is equipped with solar panels, ensuring energy independence, which stands as a positive example of integrating green technologies into educational projects.

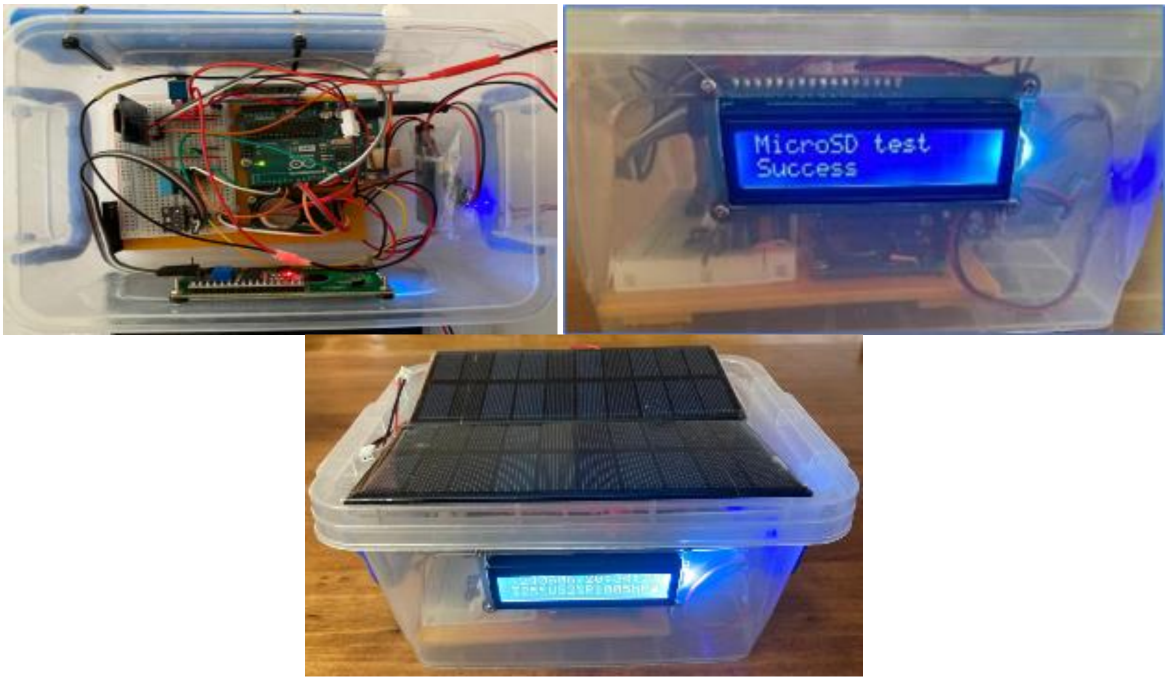

Fig. 1. Mini Weather Station - MSM 001 built on the STEM concept
(top view, side view, view with solar panel)

Through this project, students learn to apply knowledge gained in engineering, electronics, and programming to solve practical problems. This hands-on experience is crucial in mechatronics education, preparing them for the challenges of modern industry.

2.2. The role of robots and mechanisms in practical learning

Robots and mechanisms [12,13,18,19] play a central role in practical STEM education as they allow students to apply theoretical concepts in a tangible environment. Robot-based projects foster critical thinking, creativity, and problem-solving skills, enabling students to build and experiment with complex systems. This approach is part of the philosophy of STEM education, where students not only learn how to design and assemble mechanisms but also program and optimize them to perform specific tasks.
Educational programs based on robotics, such as FIRST Robotics, RoboCup, and university mechatronics competitions, contribute to the development of essential skills in the digital age. The projects often involve the integration of sensors and automated control systems, helping students understand how modern industrial processes work, including automation and intelligent production systems.
Mechanisms such as transmissions, pneumatic systems, or hydraulic systems are often used in these projects to simulate real-world processes encountered in industry. This combination of mechanical engineering and electronics stimulates multidisciplinary thinking, giving students a holistic view of how complex mechatronic devices function in real life.
An impactful European project is the **Guide of STE(A)M Education Practices - STEAM on edu**, funded by the European Union's Erasmus+ program. This guide is a valuable tool for any teacher wishing to apply the STEAM model. It provides detailed instructions for 12 study projects proposed in the guide, available at: https://steamonedu.eu/wp-content/uploads/2021/03/D4-Guide-of-STEAM-education-practices.pdf.
These 12 projects offer useful starting points for teachers interested in applying the STE(A)M approach in educational activities. Two of the proposed projects are:
(1) *Vision of the Future* and
(2) *Smart Home Sensor*.
Vision of the Future 26 involves a mini robot programmed with Scratch and Java for Arduino. In the image below (Figure 2), a presentation of the project from the aforementioned guide can be seen:
https://steamonedu.eu/wp-content/uploads/2021/03/D4-Guide-of-STEAM-education-practices.pdf.

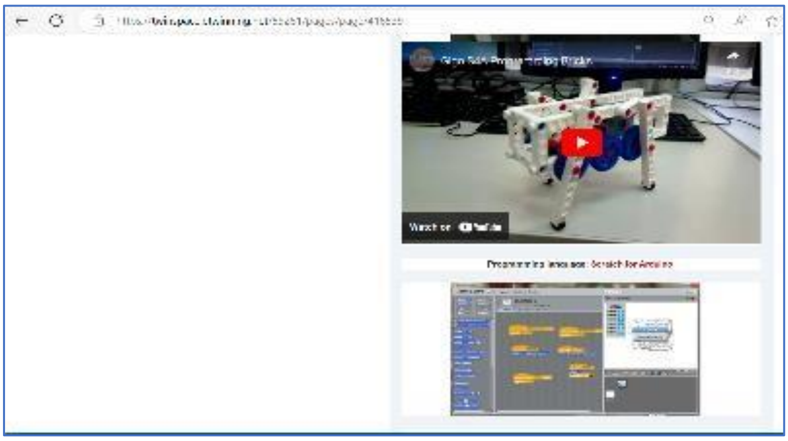

Fig. 2. "Vision of the Future," video available on YouTube

The ***Make it Open*** project, funded under the Horizon 2020 program, provides a kit for teachers with resources and examples for implementing various projects. It was one of the partners of the Bucharest Science Festival in Romania, 2023.
Arduino software has been widely adopted in STEM education programs worldwide. Its simplicity, accessibility, and versatility make it an ideal tool for introducing students to fundamental concepts in electronics and programming. Many educational institutions integrate Arduino into their curricula to teach topics such as electrical circuits, sensor interfacing, data logging, robotics, and IoT (Internet of Things) applications.

Arduino-based projects in STEM education range from simple experiments with LEDs and sensors to more complex projects like building robots, environmental monitoring systems, and smart devices.

Beginner Arduino kits for educational purposes are available on the market. These kits usually include Arduino boards, components, sensors, and educational materials such as tutorials, lesson plans, and project ideas. The beginner kits provide teachers with everything they need to introduce Arduino to students, regardless of their prior experience in electronics or programming. These kits offer hands-on learning experiences that engage students and encourage experimentation and creativity.

3. The benefits of STEM education applied to mechatronics

The application of STEM education to the field of mechatronics offers numerous benefits, enhancing both curricula and student competencies. These benefits can be summarized as follows:

1. **Improvement of the Mechatronics Curriculum:** STEM education contributes to updating and enriching the curriculum content to meet modern technological demands and increase its relevance to students.
2. **Multidisciplinary Teaching:** It leverages teaching content across multiple disciplines, combining science, technology, engineering, and mathematics, in alignment with national educational standards.
3. **Integrated Modern Principles:** It applies STEM/STEAM principles alongside up-to-date knowledge from mechatronics and contemporary technologies, promoting relevant and forward-thinking education.
4. **Engagement Activities:** It plans and organizes activities that actively involve students, parents, and the community to create a collaborative educational environment.
5. **Complex and Relevant Lessons:** It delivers periodic lessons on related sciences, emphasizing the importance of specific mechatronic concepts while ensuring age-appropriate content and participant safety.
6. **Interconnected Curriculum:** It ensures the completion of the Mechatronics curriculum while fostering connections with related disciplines for a holistic approach to science and technology education.
7. **Professional Development:** It supports the professional growth of other STEM/STEAM educators by sharing best practices and promoting effective teaching-learning methods.
8. **Tailored Projects:** It backs the development of projects that address the needs and interests of students, ensuring their relevance and applicability.
9. **Technological Applications:** It uses various complementary technological applications and diverse online resources to enhance the learning process.
10. **Increased Productivity:** It boosts productivity and learning opportunities through the use of modern technology.
11. **Improved Communication and Collaboration:** It enhances communication and collaboration within work teams, fostering essential skills for students' future careers.

• Development of Critical Thinking and Practical Skills

STEM/STEAM education promotes an active learning approach, encouraging students to engage in practical experiences that help them develop problem-solving and analytical abilities. For instance, the "FIRST Robotics" program in the United States, which encourages students to build and compete with robots, offers them the opportunity to apply theoretical knowledge in a practical and competitive setting. This learning method, focused on mechatronics and robotics, not only builds technical skills but also develops competencies such as collaboration, leadership, and creativity.

Susan Riley, an expert in STEAM education, emphasizes that "STEAM is an educational approach to learning that uses science, technology, engineering, arts, and mathematics as access points for guiding student inquiry, dialogue, and critical thinking." This definition highlights critical thinking as a key outcome of STEAM education.

• Creating Innovative Solutions through Interdisciplinary Projects

STEAM education enables the integration of various disciplines [5,10,12,13,18,19], and through interdisciplinary projects, it generates innovative solutions for complex problems. For example, projects like "Design Thinking," used by universities such as Stanford, foster innovative thinking among students, helping them collaborate and come up with ingenious solutions to intricate challenges. In this model, students not only learn technical concepts but also how to communicate and collaborate effectively, which is crucial in the modern workplace.

Globally, China is heavily investing in STEM education, recognizing the link between innovation and economic growth. This is reflected in teacher training programs that incorporate STEAM concepts to ensure students have a solid foundation and practical skills.

Similarly, in the United States, initiatives like "Educate to Innovate" reflect a national commitment to developing a competitive STEM workforce.

The large-scale introduction of the STEAM model into school curricula and extracurricular activities, supported by useful tools for teachers who have developed or will develop competencies to teach STEAM, could represent an important turning point for European education as well.

At the governmental level in Romania, the foundation for STEAM education is laid out in the "Educated Romania" project, which states: "Promoting STEAM education" includes cross-cutting strategic objectives related to "preparing and supporting teachers for teaching, learning, evaluating, and motivating students in the STEAM field."

The "Educated Romania" project has also been formalized through a package of educational laws, which includes two significant legislative acts:

● **Law on Pre-University Education No. 198/2023 (updated):** This law contains provisions aimed at improving the quality of education, including in the STEAM area. It includes measures to encourage student engagement in STEAM fields, as well as teacher preparation and support for teaching in this area.

● **Law on Higher Education No. 199/2023 (updated):** This law applies to higher education and aims to improve the academic and professional training of students. It contains specific provisions for the development of the STEAM field and the integration of Art into the teaching of STEM subjects.

Moreover, several heavily industrialized countries have launched initiatives or passed legislation to advance higher education, particularly in STEM and STEAM fields. Here are some notable examples from North America, Australia, New Zealand, the UK, China, and Japan:

☑ **United States:**

- **America COMPETES Act** (Creating Opportunities to Meaningfully Promote Excellence in Technology, Education, and Science): This act was reauthorized to increase funding for research and STEM education, specifically targeting advancements in engineering, AI, and quantum technologies. It also emphasizes collaboration between universities and industries.
- **Educate to Innovate**: A public-private initiative aimed at improving STEM education and fostering a competitive workforce, focusing on engaging women and minorities.
- **National Defense Education Program (NDEP)**: Provides scholarships and fellowships to students pursuing STEM careers, especially in defense-related industries.

☑ **Canada:**

- **Canada's Digital Charter**: This includes support for the development of a workforce skilled in new and emerging technologies like AI, cybersecurity, and quantum computing through partnerships between universities and tech companies.
- **STEM Skills Action Plan (2019)**: Focuses on integrating STEM programs at all educational levels, especially in post-secondary institutions. It encourages partnerships between universities and industries to provide practical learning experiences.

☑ **Australia:**

- **National Innovation and Science Agenda (NISA)**: This program aims to boost innovation and entrepreneurship in higher education by increasing the emphasis on STEM and industry partnerships. Funding has been allocated to research universities to foster greater collaboration with private industries.
- **Higher Education Support Amendment**: This legislation adjusts the funding model to support higher enrollment in STEM fields, which is seen as critical for Australia's economic future.

☑ **New Zealand:**

- **Tertiary Education Strategy 2020-2025**: Focuses on preparing students for future workforces, especially in STEM fields. The strategy promotes interdisciplinary education, including STEAM, and industry collaboration to better align with market needs.
- **PBRF (Performance-Based Research Fund)**: A major funding initiative that directs resources towards university research in high-demand areas, including STEM disciplines.

☑ **United Kingdom:**

- **Industrial Strategy**: The UK government launched an initiative to promote education in key areas like artificial intelligence, energy, and advanced materials. This includes significant funding for university research in STEM fields and partnerships with industries to commercialize research.
- **Turing Scheme**: Replacing the Erasmus program, this initiative focuses on sending students abroad, particularly for STEM-related opportunities, fostering global collaboration in research and education.

☑ **China:**

- **Made in China 2025**: A state-led initiative that emphasizes STEM education and aims to make China a global leader in advanced manufacturing, AI, and robotics. Significant resources have been allocated to university research and development programs in these fields.
- **Double First-Class Initiative**: This project seeks to enhance the quality of Chinese universities by focusing on specific disciplines, including STEM fields, and aiming to bring them up to world-class standards.

☑ **Japan:**

- **Society 5.0**: A government-led initiative that merges cyberspace with physical space. Universities are encouraged to innovate in fields like robotics, AI, and biotechnology. The education system is being restructured to better prepare students for these new industries.
- **Super Global Universities Program**: Focuses on enhancing the global competitiveness of Japanese universities, particularly in research and development in STEM areas.

4. Conclusions

The benefits of STEM and STEAM education are evident: they prepare young students not only for careers in science and technology but also develop their critical thinking and collaborative skills. The widespread implementation of these educational models, supported by government policies, can transform both European and international education, ultimately benefiting society as a whole by leading to generations of innovative and creative youth.
China, as a global leader in technology and innovation, has made substantial investments in STEM education to ensure that its students excel in science, technology, engineering, and mathematics. The Chinese educational system emphasizes proficiency in STEM subjects and encourages hands-on learning experiences.
The United States, with its strong tradition in research and development, prioritizes STEM education at all levels. Additionally, American universities in the STEAM fields are renowned worldwide.
National projects, such as “Romania Educated,” highlight the importance of this transition towards a skills-centered educational system focused on STEAM, ensuring a more prosperous future.
Moreover, Maia Bacovic and her team from the Faculty of Economics, University of Montenegro, Podgorica, emphasize the direct link between STEM competencies and societal well-being in their 2022 article, “STEM Education and Growth in Europe.” They state: “Statistical analysis [...] shows a strong linear association between scientific and technical education, production structure, income per capita, and productivity growth. [...] we found a significant contribution of STEM-educated workers to production growth.”
Currently, countries around the world recognize the importance of STEM education [1,4,6,7,14,15] and have undertaken various initiatives to advance this field. These efforts aim to prepare youth and students for the demands of the future workforce by aligning higher education with emerging technologies and modern Industry 4.0.

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