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THE ROLE OF THE VIRTUAL LABORATORY IN TEACHING STEM SCIENCES

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Abstract. This article analyzes the effectiveness of organizing education based on the STEM approach, in particular, teaching mathematics, biology, technology and physics through a virtual laboratory platform. It also considers the possibilities of obtaining real-time data through sensors and integrating them into the learning process. The article is aimed at forming interactivity, practical skills, interdisciplinary connections and a problem-oriented approach through the use of virtual tools in teaching, and is enriched with experimental results.

Keywords: STEM, virtual laboratory, sensor, mathematics, technology, biology, physics, integration, interactive teaching

In the 21st century, the rapid advancement of educational technologies has brought about fundamental transformations in teaching and learning processes across the globe. The emergence of new pedagogical paradigms has required educators to move beyond traditional methods and embrace more integrative, student-centered, and competency-based approaches. One of the most progressive and impactful of these is the **STEM education model**, which integrates Science, Technology, Engineering, and Mathematics into a cohesive interdisciplinary framework. Rather than teaching these subjects in isolation, STEM emphasizes their interconnectedness and real-world application, aiming to prepare students for the demands of a technology-driven society. The STEM approach not only enhances subject-specific knowledge but also develops essential 21st-century competencies, such as critical thinking, analytical reasoning, creative problem-solving, and technological literacy. Students are encouraged to approach challenges with an investigative mindset, explore solutions through experimentation, and make informed decisions based on evidence and logic. As a result, STEM-based education significantly contributes to the formation of scientifically literate, innovative, and adaptive individuals who can effectively address complex societal and environmental issues.

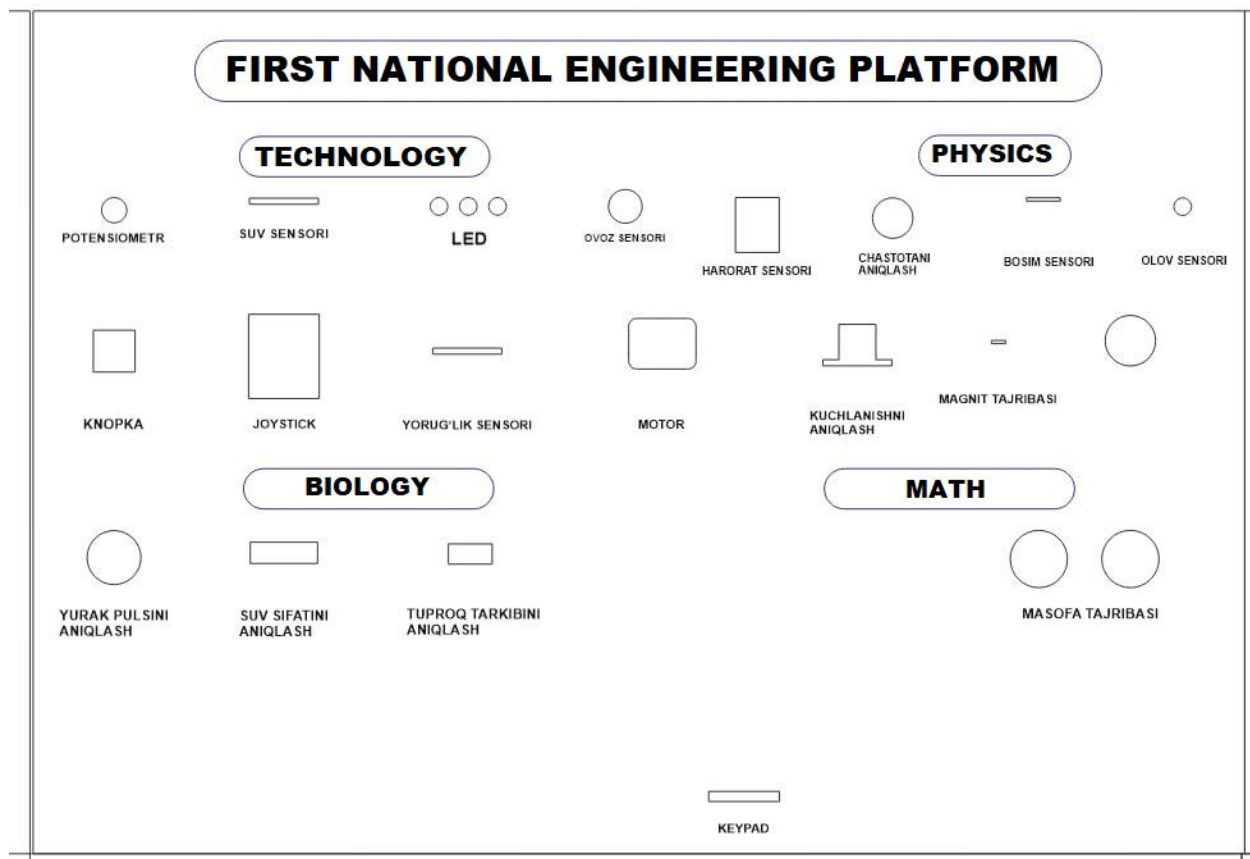
Within this framework, **virtual laboratory platforms** have emerged as a powerful and innovative educational tool. These digital environments simulate real laboratory conditions, enabling students to conduct virtual experiments, manipulate variables, observe outcomes, and engage in scientific inquiry without the constraints of time, location, or physical resources. Virtual labs offer a safe, accessible, and cost-effective alternative to traditional labs, especially in educational institutions that face limitations in terms of equipment, materials, or infrastructure. These platforms facilitate interactive, hands-on learning experiences that reinforce theoretical concepts through practical application. For



Date: 13th July-2025

example, students studying physics can simulate motion experiments, biology students can explore cellular processes in 3D, and mathematics learners can visualize geometric transformations dynamically. The use of real-time feedback, data analysis tools, and immersive visuals enhances student engagement and deepens conceptual understanding. Furthermore, virtual laboratories play a vital role in promoting educational equity. By providing universal access to high-quality scientific experimentation tools, they bridge the gap between resource-rich and resource-limited schools. This is particularly important in developing countries or rural areas, where physical laboratories may be scarce or outdated. In such contexts, virtual labs serve not only as a substitute but as a transformative solution that expands the horizons of science education.

The First National Engineering Platform is an innovative and integrated educational system developed to modernize and enhance STEM (Science, Technology, Engineering, and Mathematics) education by combining theory with hands-on experimentation using real-time digital sensors and microcontroller-based technologies. Designed to support both general and specialized school curricula, this platform facilitates multidisciplinary learning through a structured layout divided into four main branches: Technology, Physics, Biology, and Math. Each branch encompasses specific components and sensor-based modules tailored to develop subject-specific competencies while fostering 21st-century skills such as analytical thinking, digital fluency, problem-solving, and interdisciplinary collaboration.



Picture 1. *The First National Engineering Platform*

Date: 13th July-2025



The **Technology** section serves as the core of engineering-related exploration, equipping students with the tools to understand and control basic electronic and electromechanical systems. This segment includes key modules such as the *potentiometer*, which is used to vary resistance and control analog input values in circuits; the *water sensor*, which detects the presence or level of moisture and is applicable in smart irrigation systems; and *LEDs*, which illustrate digital outputs and are essential in understanding basic binary signaling and visual indicators. The *sound sensor* enables the measurement of ambient noise or specific acoustic signals, supporting projects in audio control or environmental monitoring. Manual control devices like the *button* and *joystick* introduce fundamental user interface operations and basic programming logic, allowing students to simulate control systems used in robotics or gaming. The *light sensor* detects ambient light intensity, which is useful in projects related to automation and smart lighting systems. A *motor* is also included to transform electrical energy into mechanical movement, often integrated into robotics and automation projects. Additionally, a *keypad* allows for multi-digit input or command sequences, enabling students to build access control systems or coded input interfaces. In the **Physics** section, learners are introduced to practical applications of core physical principles through data-gathering tools that allow real-time observation and experimentation. The *temperature sensor* plays a crucial role in thermal studies, allowing students to monitor heat changes during various chemical or physical reactions. The *frequency measurement module* helps learners understand oscillatory phenomena such as vibrations, alternating current, and waveforms. *Pressure sensors* are used to measure force applied per unit area and are instrumental in fluid mechanics, gas laws, and force studies. The *flame sensor* identifies infrared radiation typically emitted by fire, which introduces students to the science of radiation and combustion detection technologies. The *force measurement module* helps students analyze mechanical interactions, Newton's laws, and load testing, while the *magnetic experiment* module visually and electronically demonstrates magnetic field interaction, attraction, and repulsion, supporting the study of electromagnetism and magnetostatics.

The **Biology** section provides essential tools for studying life sciences in an experimental format, helping students explore human physiology and environmental conditions with the aid of modern sensor technology. The *heart pulse sensor* measures pulse rate and is an entry point into the study of the human circulatory system, biofeedback, and health-monitoring technology. The *water quality analysis module* detects parameters such as turbidity, conductivity, and pH, which are crucial for environmental biology and public health. Similarly, the *soil composition analyzer* provides insights into the mineral and moisture content of soil, allowing students to understand ecosystem health, plant nutrition, and agricultural sustainability. These experiments encourage eco-literacy and the scientific analysis of living environments. The **Mathematics** section, while often perceived as abstract, is made tangible and engaging through the inclusion of a *distance measurement experiment*, typically using ultrasonic or infrared sensors to calculate lengths, depths, or spatial relationships. This feature helps visualize key concepts in algebra, geometry, trigonometry, and applied physics. Students can calculate object distances,

Date: 13th July-2025

analyze rates of change, and apply geometric theorems to real scenarios, turning theoretical mathematics into active inquiry.

Overall, the *First National Engineering Platform* is more than just a teaching toolkit; it is a robust, multifunctional educational innovation that brings the concept of smart classrooms and digital laboratories into reality. It empowers teachers to create dynamic, student-centered lessons, and enables learners to explore scientific principles through project-based learning, hypothesis testing, and collaborative experimentation. The platform also supports inclusivity by providing virtual access to advanced scientific instruments in settings where physical labs are limited or unavailable. By doing so, it addresses the global need for equal access to high-quality STEM education and prepares a new generation of students to enter higher education and the workforce with confidence, creativity, and a strong foundation in science and technology.

