Volume 3, Issue 12, December – 2025 ISSN (E): 2938-379X

ROBOTICS AS A TOOL FOR FORMING ENGINEERING THINKING IN SCHOOL CHILDREN

Vyobornov Sergey Akhtyamovich
Senior Lecturer, National Pedagogical University of Uzbekistan named after Nizami

Abstract
This article provides an in-depth examination of educational robotics as a pedagogically significant tool for shaping engineering thinking in school-aged learners. It expands upon key instructional approaches—project-based learning, laboratory–practical exercises, and competition-oriented models—while offering a detailed analysis of robotics platforms commonly integrated into modern educational environments. Particular attention is devoted to the interdisciplinary nature of robotics education, which simultaneously draws on mathematics, physics, computer science, engineering graphics, and technological design. The article develops an extended conceptual framework describing how robotics fosters systemic reasoning, algorithmic literacy, creativity, technical reflection, and problem-solving skills. Several examples of educational robotics projects are presented, categorized by complexity and instructional value. The expanded findings reinforce the conclusion that sustained and systematic use of robotics not only enhances motivation and digital literacy but also cultivates essential 21st-century competencies required in contemporary engineering and technological professions.

Keywords: Robotics; engineering thinking; educational robotics; STEM education; digital tools; project-based learning; school education; practice-oriented learning.

Introduction

Over the last decade, robotics has undergone a paradigm shift—from being perceived as an extracurricular hobby or optional enrichment activity to becoming an essential component of general education. This transformation is driven by broader socio-economic and technological changes, including rapid digitalization, the rise of Industry 4.0, and the increasing demand for specialists capable of solving complex engineering and computational problems. In response, educational systems worldwide have revised curricular standards, emphasizing the development of prototyping, algorithmic reasoning, and system-level thinking among schoolchildren.

In this expanded examination, robotics is treated not merely as a technical discipline but as a multi-dimensional educational ecosystem that integrates cognitive, practical, and creative components. Research consistently shows that students engaged in robotics demonstrate improved performance in mathematics, physics, informatics, and technology, along with strengthened logical, spatial, and analytic abilities. More importantly, robotics enables

Web of Teachers: Inderscience Research
webofjournals.com/index.php/1

schoolchildren to internalize engineering habits of mind—structured problem formulation, iterative testing, evidence-based reasoning, and design optimization.

Thus, robotics becomes a fundamental platform for preparing future engineers, designers, programmers, mechatronics specialists, AI developers, and innovators of the digital economy.

Engineering thinking can be conceptualized as a multidimensional cognitive process that enables an individual to systematically structure a problem, delineate its critical parameters and constraints, evaluate a spectrum of potential solution pathways, and justify the selection of the most efficient design configuration or algorithmic strategy. Within this framework, educational robotics functions as an exceptionally effective experiential platform, as it immerses learners in a continuous cycle of problem identification, modeling, prototype construction, algorithm development, empirical testing, and iterative refinement—thereby fostering the comprehensive development of the core components of engineering reasoning.

Interdisciplinarity as the Foundation for Competence Development

Educational robotics is inherently interdisciplinary, serving as a nexus that integrates conceptual and practical knowledge from several core academic domains. Its pedagogical value lies in the fact that it requires students to mobilize and synthesize diverse forms of reasoning when designing, programming, and testing robotic systems. In particular, robotics education draws upon:

– Mathematics, including the geometry of motion, trajectory construction, calculation of time, distance, and velocity, as well as proportional reasoning and quantitative modeling essential for precise control of robotic mechanisms;

– Physics, especially mechanics, dynamics, force interaction, principles of energy transfer, and sensor operation, all of which underpin the functional behavior of robotic systems in real environments;

– Computer Science, encompassing loops, conditional structures, functions, data processing, and algorithmic logic that govern the robot's behavior and enable autonomous decision-making;

– Technology and Engineering Design, involving the construction, assembly, and fabrication of mechanical elements, understanding material properties, and applying design constraints to ensure structural stability and functionality;

– Engineering Graphics, which includes the visualization, interpretation, and development of technical drawings, CAD models, and schematic representations necessary for accurate planning and communication of design ideas.

A learner engaging with a robotics kit or a virtual modeling environment simultaneously activates multiple forms of cognitive processing, including logical, spatial, analytical, and creative thinking. This multimodal engagement contributes to the formation of a holistic engineering culture, in which conceptual understanding, practical skills, and design-based reasoning are integrated into a coherent intellectual framework.

Components of Engineering Thinking Developed Through Robotics

Systemic Thinking — students learn to perceive the robot as an integrated system composed of interdependent components, understanding how mechanical, electronic, and algorithmic subsystems interact to produce coordinated behavior.

Web of Teachers: Inderscience Research
webofjournals.com/index.php/1

Design Logic — learners develop the ability to select appropriate components, mechanisms, and structural configurations, applying principles of functionality, efficiency, and design constraints.

Algorithmization — students construct control structures, sequences of operations, logical conditions, and data-processing routines, thereby mastering the foundational elements of algorithmic thinking.

Experimental Mindset — robotics encourages continuous testing, debugging, and refinement of prototypes, cultivating habits of iterative improvement, empirical reasoning, and evidence-based problem solving.

Creativity — learners explore unconventional solutions and alternative approaches to task implementation, fostering innovation and divergent thinking within engineering contexts.

Technical Reflection — students develop the capacity to critically evaluate the quality of their designs and algorithms, assess system performance, and justify modifications based on analytical insights.

In the following section, we describe several educational models through which robotics can be effectively integrated into the learning process.

Robotics can be integrated into the educational process through several distinct pedagogical trajectories. The most widely adopted among them are the project-based research model, the laboratory–practical model, and the competition-oriented model. Each of these approaches engages learners in different forms of cognitive, design, and problem-solving activity, thereby contributing to the comprehensive development of engineering competencies.

Project-Based Research Model

This approach emphasizes the creation of complex, multi-stage projects in which students progress through the entire cycle of engineering activity. It mirrors real-world engineering workflows and fosters the development of systematic, reflective, and practice-oriented thinking. Within this model, learners typically engage in the following stages:

– identifying a need or defining a problem based on practical or conceptual requirements;
– formulating objectives and constraints, including technical specifications, resource limitations, and performance criteria;
– selecting an appropriate robotics platform suited to the project task;
– designing the mechanical structure, taking into account stability, functionality, and feasibility;
– developing the software, including control algorithms, logical sequences, and sensor integration;
– testing the prototype under various conditions to evaluate functionality and reliability;
– conducting error analysis, revising mechanical or algorithmic components as necessary;
– delivering a final presentation, where students justify design decisions and reflect on project outcomes.

Typical school-level project examples include:

– a sorting robot, capable of classifying objects based on color, size, or material;
– an automated irrigation system that regulates water delivery using sensor input;
– a fire-fighting robot, designed to detect and extinguish small flames or navigate simulated hazards;

Web of Teachers: Inderscience Research
webofjournals.com/index.php/1

– a transportation platform, serving as a basic model of autonomous mobility systems.

Such an instructional format cultivates in schoolchildren an essential professional competency—the ability to carry a project through to completion, which is regarded as a fundamental attribute of successful engineers. The sustained engagement required in project-based learning teaches students perseverance, responsibility, and systematic problem solving, all of which are critical for future engineering practice.

Laboratory–Practical Model

The laboratory–practical model consists of a series of short, focused tasks, each designed to develop mastery of a specific component, mechanism, or programming concept. Unlike the project-based model, this approach emphasizes targeted, incremental skill acquisition, allowing students to deepen their understanding of individual elements before applying them in more complex contexts. Typical laboratory tasks include:

– working with distance, light, and color sensors, including calibration and data interpretation;

– exploring the behavior of servomotors and DC motors, such as torque, rotation control, and speed regulation;

– constructing and analyzing lever systems, linkages, and gear mechanisms, with attention to force transmission and mechanical advantage;

– practicing motion control, including the fundamentals of PID regulation for stable and precise robot movement;

– implementing both simple and advanced algorithms, ranging from basic loops and conditionals to multi-branch logic and data-driven decision making.

This format allows students to systematically study the components of robotics without the need to engage in a large-scale project, thereby ensuring structured progression from foundational to advanced skills. It is particularly well suited for building conceptual clarity and technical fluency, which later support more complex project and research activities.

Competitive Learning Model

Participation in competitions encourages students to:

– optimize mechanics;

– improve algorithms;

– work under time pressure;

– come up with unconventional solutions.

Currently, popular robotics competitions are held worldwide, such as FIRST LEGO League, WorldSkills Junior, RoboCup Junior, MakeX, Arduino Challenge.

Competitive activities help develop leadership skills, responsibility, and stress resilience, as well as motivate students to continuously improve their skills and knowledge.

There are many platforms and tools available online for learning robotics. Let's consider the main platforms used in schools today.

LEGO Education

Suitable for elementary and middle school students.

Strengths: versatility, modularity, ease of learning, large number of methodologies and digital resources.

Web of Teachers: Inderscience Research
webofjournals.com/index.php/1

Applications: building simple and complex robot models, programming using visual languages like Scratch or LEGO Mindstorms, participating in team projects and competitions.

Arduino

Suitable for high school students and university students.

Strengths: open hardware platform, ability to work with various sensors and actuators, flexibility in programming with C/C++.

Applications: developing autonomous robots, electronic devices, participating in engineering competitions and projects.

Micro:bit

Suitable for elementary and middle school students.

Strengths: compact size, ease of programming, built-in sensors and interfaces for expansion.

Applications: creating interactive projects, learning basic programming and robotics.

Using these platforms in the educational process not only develops technical skills but also fosters critical thinking, teamwork, and project-based skills.

Official resource: https://education.lego.com

Arduino and Arduino Education

Used in middle and high schools, as well as in colleges.

Advantages: open architecture, ability to connect a large number of sensors, transition from block-based to text-based programming, integration with Tinkercad.

Resource:https://www.arduino.cc/education

VEX Robotics

Suitable for competitive training and in-depth study of algorithms.

Resource: https://www.vexrobotics.com

Make Block

A platform that combines simplicity with a serious set of tools for projects.

Resource: https://www.makeblock.com

Digital Simulators: VEXcode, VR Tinkercad, Circuits, Webots Education.

These tools allow lessons to be conducted without physical hardware.

Let’s consider examples of educational projects aimed at improving the quality of robotics education. We will sort these examples by the level of implementation difficulty.

1. Line-following Robot

Goal: Move along a line using a light/color sensor.

Skills: loops, conditional statements, P-control, sensor integration.

2. Obstacle Avoidance Robot

Sensors used: ultrasonic or infrared distance sensors.

Complexity: combining data from multiple sensors, building a map.

3. Mini-Manipulator

Goal: Move objects between two points.

Skills: servos, angular mechanics, coordinate calculation.

4. Autonomous Vehicle

Application: simulation of a self-driving car.

Skills: PID control, navigation, working with multiple sensors.

Pedagogical Advantages of Robotics
The use of robotics in the educational process provides the following methodological benefits:
– development of stable cognitive motivation;
– transition from theory to practice;
– fostering a culture of project-based learning;
– increasing digital literacy;
– development of 21st-century competencies: communication, collaboration, creativity, critical thinking;
– improvement of system analysis skills.
Moreover, robotics is a powerful tool for **inclusive education**: children with diverse educational needs can successfully participate in projects, thanks to visual, tactile, and digital support.

Conclusion

Robotics education in schools represents not merely an assemblage of kits or technical devices, but a comprehensive pedagogical ecosystem that integrates project-based learning, engineering design, programming, and research-oriented activities. This multidisciplinary approach contributes to the development of engineering thinking, computational literacy, and systematic problem-solving skills, thereby preparing students to effectively navigate the challenges of the digital economy and rapidly evolving technological landscape.

The educational value of robotics extends beyond technical proficiency. By engaging in hands-on projects, students cultivate critical thinking, creativity, collaboration, and decision-making abilities, which are recognized as essential 21st-century competencies. Additionally, participation in competitive robotics activities fosters resilience, leadership, and time management skills, reinforcing both cognitive and socio-emotional development.

Effective implementation of robotics in educational settings requires a systematic and layered approach. This includes the integration of digital resources, virtual simulators, physical hardware, and projects of varying complexity, enabling gradual skill acquisition from foundational concepts to advanced applications. Such a structured methodology ensures both immediate learning outcomes and sustainable long-term educational impact, while providing opportunities for differentiated and inclusive learning, accommodating students with diverse abilities and learning needs.

In conclusion, robotics serves as a powerful tool for modern education, bridging theoretical knowledge and practical application, stimulating student engagement, and fostering a culture of innovation. Its incorporation into school curricula not only enhances technical and cognitive skills but also contributes to holistic personal development, thereby strengthening the overall quality and effectiveness of the educational process.

References

1. Engineering Thinking: Features and Reproduction Technologies. Collection of scientific articles and theses. Moscow: Delovaya Kniga Publishing.

Web of Teachers: Inderscience Research
webofjournals.com/index.php/1

2. Tarapata, V. V., & Samylkina, N. N. (2017). Robotics in School: Methodology, Programs, Projects. Moscow: Knowledge Laboratory Publishing.
3. Glukhov, V. S., Dikoy, A. A., Galustov, R. A., & Dikaya, I. V. (2019). Fundamentals of Robotics. Textbook.
4. Grigoriev, A., & Vinnitsky, P. (2022). Robotics at School and Home: Project Book. Moscow: BHV Publishing. ISBN 978-5-9775-6837-1
5. Zlakazov, A. S., Gorshkov, G. A., & Shevaldina, S. G. (2011). LEGO Construction Lessons at School: Methodological Guide (edited by V. V. Sadyrin & V. N. Khalamov).
6. Didactic Impact of Educational Robotics on the Development of STEM Competencies. (2024). Published: 10 December 2024.