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# INTEGRATING ROBOTS IN EDUCATION WITHIN THE AI CONTEXT

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**Abstract.** Robots, along with AI and VR technologies, are among the most compelling tools in education. While technology providers highlight innovative learning opportunities, scholars discuss various ways of integrating robots, either within specific subjects such as informatics and programming, or for developing more general social skills. Numerous case studies demonstrate fragmented practices of using robots in schools and universities, overlooking their broader role in preparing new generations for the future of work. At the same time, many educational institutions explore practical and conceptual questions for providing training on robotics, ranging from investments in hardware and teacher training, to benefits for learning, future skills, teaching methodologies, among others. The objective of this paper is to investigate some of the key challenges and opportunities for integrating robots in educational settings. Based on a literature review, it critically examines the main issues educators face to understand how, why, and to what extent robots might be integrated in teaching and learning. Building on Bloom's taxonomy, the purposes and opportunities of using robots in class are carefully evaluated, taking into consideration as well their impact on innovative teaching and assessment. A special section is dedicated to the development of educational robotics in Bulgaria. Findings of this study indicate that a more holistic perspective is needed to prepare students not only to work with robots, but also to design, evaluate, and critically analyse their role in the near future. The discussion evaluates more strategic views about using robots in education. The conclusion and future work sections outline the next steps in defining the new roles of robots in education.

*Keywords:* Robots in Education; Educational robotics; Robots in Learning and Teaching; Bloom Taxonomy; Teaching Methodologies.

## 1. Introduction

The interest in educational robots (ER) has sharply increased during the last decades. The systematic analyses of (Lu et al., 2025 and Darmawansah et al., 2023) revealed the changing scope in the research publications, from

ER effectiveness, students' skills, and teachers' professional development, to raising automation and artificial intelligence skills. The recent advances in AI technologies highlight the needs for robot-related skills to support next generations for the challenges and realms of the future of work.

Integrating ER in education is a complex process, requiring investments in hardware equipment, teacher training, organisational and curriculum arrangements. From this perspective, the present research aims to explore the roles and objectives of ER implementation in educational institutions. Building on a structured literature review, the paper critically examines the main factors affecting ER, and steps on the Bloom's taxonomy to evaluate future-oriented skills by using robots in class.

Based on the paper's objectives, the following research questions are defined:

- RQ1: What are the main pedagogical roles attributed to ER in literature?
- RQ2: How ER can support the development of cognitive and future-oriented skills, based on the Bloom's taxonomy?
- RQ3: How educational institutions can use ER to support learners in preparing for the future?

In the background section is presented a structured literature review, along with PRISMA analysis. Next is presented the role of the Bloom taxonomy for ER. A desktop analysis reveals the state of ER in Bulgaria, and qualitative analysis of experts' interviews demonstrate the raising interest for ER. The discussion points out on strategic insights for ER.

## 2. Background

Robots today are used both in formal and informal education (Ribeiro & Lopes, 2020), but best practices, practical problems and recommendations for teachers and educational institutions are rarely discussed in literature. ER is taught from kindergarten and primary school, to secondary school, university and informal education (Anwar et al., 2019).

### *2.1. Defining Educational Robots*

The ER papers often do not provide definition of an "educational robot" from a technological point of view. Authors, such as Malinverni et al. (2021)

differentiate virtual robots and physical robots, while others mainly use the terms "educational robot" and "robotics" as generally accepted concept.

**Technological view.** ER can be classified into pre-build robots, programmable robots, humanoid robots, and modular robots, as summarized in Table 1 (Gümüş et al., 2023). A detailed analysis of robotic platforms and developing environments is provided in (Ribeiro & Lopes, 2020).

**Table 1**. Educational robot types and characteristics

| Robot Type | Key Characteristics | Educational Use | Target Learners |
|---|---|---|---|
| **Pre-built robots** | Simple, toy-like robots predefined pre-configured behaviors; easy to use | Basic computational thinking | Kindergarten, primary education |
| **Programmable robots** | Users can control behavior coding, sensors, actuators, control systems, custom commands. | Teaching robotics, STEM concepts, problem-solving through coding | Primary to secondary education |
| **Humanoid robots** | Advanced robots, resembling human form & movement, human-like structure (arms, legs, head); complex motion. | Understanding robotics, balance, motion & locomotion | Secondary and higher education |
| **Modular robots** | Robots composed of modules, reconfigurable design; multiple assembly options; kit-based structure | Mechanics, engineering, kinematics and dynamics | Secondary and higher education |

The review by (Anwar et al., 2019) briefly outlines the history of ER, highlighting the advent of the mass market ER Mindstorm®, built from the collaboration between LEGO Group and the Massachusetts Institute of Technology (MIT). From 1998 to 2022, LEGO Mindstorms® dominated the educational landscape, covering hardware and software elements, learning resources and competitions. Most of the ER literature focused on LEGO MINDSTORMS® and LEGO platforms (RCX, WeDo, EV3 model). Alternative platforms such as VEX robotics, Robotic Bioloid, Arduino-based robotic kits, iRobot Create, and Nao are rarely discussed. Block-based programming Robolab (LEGO), Scratch, Alice, Google Blockly are used as SDK environments for ER (Ribeiro & Lopes, 2020), along with traditional

C/C++, Java, Python, MATLAB Robotics Toolbox. Arduino IDE and libraries are reserved for Arduino-based robot platforms (Darmawansah et al., 2023, Ribeiro & Lopes, 2020, Malinverni et al., 2021).

**Social view.** An important aspect about "*what is a robot*" is evoked by Shute et al., (2017), analysing children's views about robots. The authors find out that children get their understanding about "*what is a robot*" consistently from media, and link robots with narratives of violence and fights. Thus, robot is not just a "tool" or an "instrument", as it has anthropomorphic characteristics. The media narratives about robots dominate children meaning construction, even when they have personal experiences in ER. Ethical and social discussions about robots are often neglected in mainstream education. Thus, students' prejudices and preconceptions about "*what is a robot*" and "*what a robot can do*" can frame their further experience with robots (Shute et al., 2017), raising important concern in ER.

### *2.2. The roles of ER*

Generally, the robots in education can be classified into two large categories: "robot as a learning object" and "robot as a learning tool" (Yanış & Yürük, 2020).

- Robot as a learning object. All educational activities are focused on studying the robot itself. The main question is "*what is a robot*" and students approach and investigate the robot as a complex intelligent tool, which consists of hardware elements, movable parts, sensors and computational modules.
- Robot as a learning tool. The robot is used as a media to learn content knowledge (e.g., STEM). Thus, it serves to improve understanding, knowledge retention, increasing students' motivation and engagement. The main question is "*what a robot can do*". Most of the papers focus on ER for improving STEM learning (such as programming, mechanics, etc.), while supporting development of transversal skills, such as problem solving, creative thinking, teamwork, cooperation and others (Lu et al., 2025; Darmawansah et al., 2023; Ribeiro & Lopes, 2020).

An additional class of ER is formed by "social robots", defined as robots that can deliver learning experiences through social interaction with learners

(Belpaeme et al., 2018). The robot-assisted learning can be implemented in the following three settings:

- Robot as a tutor or teacher (teaching assistant). The role of the robot is to facilitate or assist the teaching process. This scenario presents the robot as a personalized tutor or a one-to-one instructor, mainly for children with special educational needs.
- Robot as a peer learning companion. Imitating peer-to-peer interactions, the robot is presented as a more knowledgeable peer, guiding the student along the learning trajectory.
- Robot as a novice. Robot is put in the role of a novice, allowing students to take the role of an instructor. This is an instance of "learning by teaching". For example, a humanoid robot helped vocabulary learning in pre-school English classes in Japan (Belpaeme et al., 2018).

### *2.3. Learning approaches with ER*

The main teaching and learning approaches for introducing ER are active-learning, where students learn and construct new knowledge through inquiry, exploration, and prior experiences (Anwar et al., 2019). The implementation of ERs builds on the theories of constructivism and its later modification – constructionism (Ackermann, 2001). In constructivism learners build new knowledge by working on authentic problems in small groups. The constructionism is similar, but emphasize on the importance of real-world contexts and in-situ intelligence (situational constructionism) (Ackermann, 2001).

An important pedagogical aspect of ER is to develop computational thinking skills (Yanış & Yürük, 2020), defined as the ability to "solve problems, design systems, and understand human behaviour, by drawing on the concepts fundamental to computer science". Thus, integrating ER aims to improve students' skills to decompose problems, construct systems and derive solutions, while also excelling at programming, debugging, iteration and generalization (Yanış & Yürük, 2020).

## 3. Methodology

A PRISMA analysis of the research literature outlined the published works in ER between **2023 – 2025, c**onsidering the importance of GenAI on current research[1]. It covers the academic databases Scopus, WoS, IEEE Xplore, focusing on peer-reviewed articles and conference proceedings. The key words and combinations are: *"educational robot/s", "robot/s in education*", *"educational robotics"*, *"robotics in education",* and *"robot-support learning".* The search strategy combined keywords related to "educational robotics" and learning contexts using Boolean operators (AND, OR). The PRISMA diagram in Figure 1 explains the selection process. The inclusion criteria are publication in peer-reviewed journals/conferences, clarity of methodology, empirical evidence, and ER in formal and informal education. Excluded papers cover topics such as parents' attitudes, ER competitions, ICT training and others.

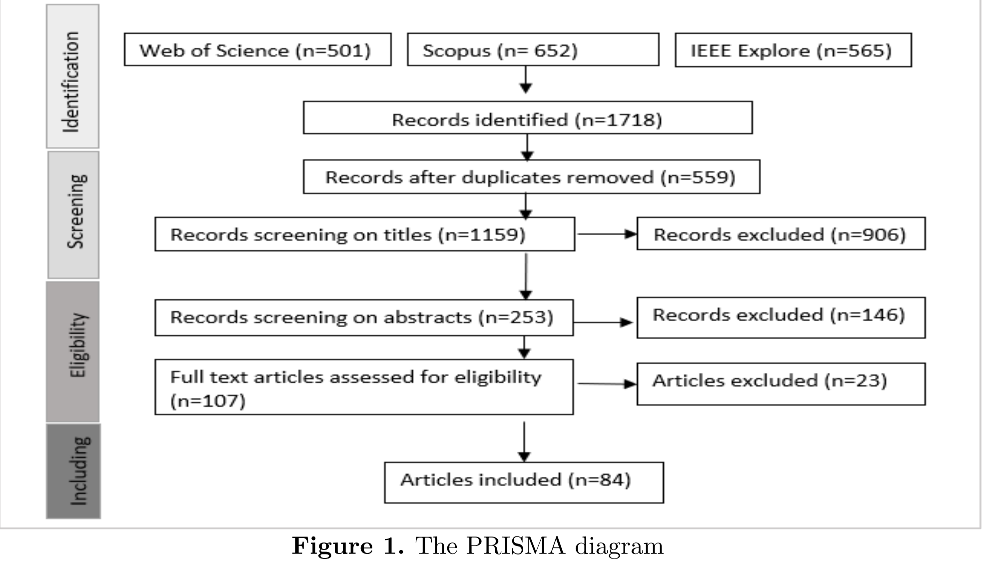


**Figure 1.** The PRISMA diagram

In total 5 main topics emerged, covering both pedagogical and technological themes: pedagogical integration and curriculum design (problem and project-based learning, STEAM, etc.); cognitive development & computational skills; learner engagement; instructional and technological settings and teacher training. Table 2 provides a short summary and description of the main topics and areas in ER.

**Table 2**. Main themes in ER

| Theme | Description | Sub-issues | Example studies |
|---|---|---|---|
| Pedagogical integration & curriculum design | How ER is embedded in formal/informal education systems | curriculum alignment, instructional models (PBL, inquiry-based learning), STEAM, lesson design | Torres et al. (2025) |
| Computational thinking & cognitive development | Robotics as a tool for developing CT and reasoning skills | problem decomposition, computational and algorithmic thinking, debugging, abstraction | Costa Junior et al. (2024), Hijón-Neira et al. (2024) |
| Learner engagement & affective outcomes | Emotional and motivational impact of robotics learning | engagement, enjoyment, self-efficacy, gamification, attitudes toward STEM | Zviel-Girshin, Rosenberg, N. (2025) |
| Teacher readiness & professional development | Teachers' ability to adopt robotics in practice | PCK, training programs, self-efficacy, attitudes, orchestration skills | Mâţă, Tzafilkou (2025) |
| Robotics platforms, tools & technological design | Types of systems used in education | Arduino, LEGO, simulation platforms, humanoid robots, mobile robots | Barradas et al. (2024) |

## 4. Exploring current challenges and opportunities for ER

Among the main challenges in education are currently evoked by GenAI technologies[1]. While they can play a useful role in empowering learners and lecturers (Mollick & Mollick, 2023), the corporate report of Anthropic[2] provides observations that students prefer to "outsource" to GenAI learning tasks, requiring high-order thinking skills hindering learning and skills development.

### *4.1. ER, skills and Bloom taxonomy*

Bloom's taxonomy in Table 3 facilitates the description of how robots can help students to develop knowledge and skills for the future, both as a "learning object" and as a "learning tool".

**Table 3**. Bloom taxonomy and ER

| Bloom level | Robots as learning objects | Robots as learning tools |
|---|---|---|
| Remembering (recall facts, concepts) | Identify robot components (sensors, actuators, controllers). Label parts. | Recall examples of robot use in real-world scenarios and sectors (agriculture). |
| Understanding (explain ideas, interpret, classify) | Explain how a sensor input affects robot movement, differences between robots. | Explore and classify robots by task and by design. |
| Applying (use knowledge in new situations) | Program a robot to avoid obstacles. Apply geometry concepts by having robots navigate grids. | Build a prototype of a robot for a sustainability challenge (e.g., sorting recyclable materials). |
| Analysing (differentiate, compare, examine relationships) | Debug robot behaviour, analyse sensor errors vs. code logic. Compare AI vs. rule-based robot navigation. | Analyse competitive robot designs: what design trade-offs can make one robot more suitable for specific tasks? |
| Evaluating (justify, critique, make decisions) | Debate robots replacing human tasks (e.g., in healthcare.). Peer evaluation and testing. | Ethics workshop: evaluate ethical implications of autonomous decision-making robots. |
| Creating (design, innovate, build something new) | Open-ended project: design a robot to solve a school problem (e.g., automate attendance). Design creative robots. | Participate on robot competitions and create autonomous robots. STEAM projects: build robots for societal challenges (smart agriculture, monitoring). |

### *4.2 . Evolution of Skills, Teaching and Assessment*

Traditionally, the ER courses curriculum include common topics such as (1) how robots work: actuators, sensors, microcontrollers; (2) movement and locomotion: hands, wheels, legs, drones; (3) sensors (ultrasound, infrared, vision, touch, gyroscopes) and data (data collection, analysis and AI); (4) advances in robot applications: healthcare, agriculture, logistics, space; and (5) ethical issues, privacy and safety. Adding AI topics in ER leads to classes on: (1) sensing, (2) acting, (3) representation, (4) reasoning, (5) learning, (6) collective AI and (7) ethical and legal aspects (Bellas et al., 2024).

To attract different learners to robotics, Rusk et al. (2008) propose the following four strategies: implement robot projects focused on themes instead of challenges; design projects combining art and engineering;

emphasize projects encouraging storytelling; and organize exhibitions, rather than competitions.

The main form of assessment in ERs is authentic, portfolio-based, performance-oriented evaluation where students are graded not just on "what works," but on how they think, collaborate, and innovate.

The topics of ER and AI/GenAI gradually converge to assume more practical applications and automation projects (Lu et al., 2025). In this respect, Table 4 demonstrates how integrating robotics and AI can form new skills needed for the future, shifting the focus toward system thinking, managing intelligent systems and solving real-world problems. It is important to outline that ethical issues should be mapped to each level of the Bloom taxonomy.

**Table 4**. Learning robots as a way to develop skills for the future

| Critical skills for the future | Evolution of skills | Examples of robot-related skills |
|---|---|---|
| System-Level Thinking | From coding to orchestrating systems | Skill to understand how robotics systems, AI, IoT, and cloud interact in complex systems. |
| Design Human–Robot Interaction (HRI) | From writing programs to shaping experiences | Skills to design intuitive, safe, user-centered interactions with robots. |
| Critical & Ethical AI/Robotics Literacy | From debugging code to questioning systems. | Skills for raising ethical questions: what robots "should" do vs what they "can" do. |
| Creative Problem-Solving & Innovation | From solving predefined tasks to new inventions. | Skills to create new applications and design better robotics solutions for dealing with real-world problems. |
| Data Literacy & AI Integration. | From writing algorithms to interpreting AI. | Skills to manage, curate, and critically evaluate the data that drives robotics and AI systems. |
| Collaboration Across Disciplines | From individual project to team-based co-creation. | Skills to set up robotics solutions in interdisciplinary fields (engineering, psychology, design, law, ethics). |

### *4.3. Challenges in integrating AI with robots*

The integration of AI with robots offers significant potential, but also introduces important technical and pedagogical challenges. ERs function as embodied, physical systems that enable hands-on interaction, supporting experiential and inquiry-based learning. In contrast, GenAI operates as a cognitive and linguistic system, facilitating content generation. While robots primarily facilitate learning through action and experimentation, GenAI supports the learning process through reasoning and explanation. Combining the two technologies can engage learners in achieving high-order learning outcomes, allowing them in writing code, better defining to problems and understanding complex interactions in the physical world.

## 5. ER in Bulgaria

### *5.1. ER in formal and informal education in Bulgaria*

The study of robotics in Bulgarian secondary education is regulated by Ordinance №15/2025 by MES[3], formally defining the educational standard for "*Robotics*" in the national qualification framework. In total eight technical universities are offering specialized educational programs in robotics and mechatronics[4]. The Institute of Robotics at BAS provides graduate PhD and MSc programs in robotics. Popular Robotics Clubs[5] are hosted by TU Sofia, (Roboclub.bg) and Burgas State University (summer camps and K–12 training programs).

In secondary education, robotics is mainly informal program, offered through extracurricular activities in robotics clubs and school STEM centres. Over the past five years, access to ER has significantly improved. The 2020 report[6] estimated that approximately 20 000 students were involved in ER activities across 31 public and private robotics clubs. More recently, 1 371 STEM centres have been established in public schools[7], supported by National STEM Centre program, providing funding educational equipment, and materials for ER[7]. According to MES, in 2023, over 3600 K-12 students learned robotics and programming, in 258 clubs across the country[8].

The national program "Robotics for Bulgaria" was launched in 2015 by SAP Labs, in cooperation with WCIF (Workshop for Civic Initiatives Foundation). Over the past 10 years, this program reached more than 270 teachers, 2800 students, and 120 schools in more than 56 cities in Bulgaria[9].

Some of the most active private robotics clubs[10], attracting students from 4 – 6 years to 16 years, are Robopartans, SparkLab, Robo Kids, Tinusaur.bg and Robotics-Biala, Academia Robotics and many others. The robotics clubs offer to K–12 students weekend classes, summer camps, and birthday parties. Local and national competitions are organised annually, bringing together between 130 – 500 students. The most popular include FIRST LEGO League, Robotics for Bulgaria, and Robot Days.

The most popular ER kits in Bulgarian clubs are LEGO Robotics, Arduino, Raspberry Pi, 3D printers, and proprietary equipment and platforms. The preschool clubs and elementary schools use KUBO, Codey Rocky, and mBot2 ER kits.

### *5.2. Qualitative insights from expert interviews*

A qualitative analysis of semi-structured interviews with five professionals outline the current situation with ER in Bulgaria. Three of the respondents have substantial experience in preschool/school robotics, and two of them are university lecturers in robotics.

The findings from the interviews indicate a clear transition of ER from a narrow technical discipline toward an interdisciplinary subject. All participants confirm that ER leads to development of problem-solving, critical and systems thinking, collaboration, and creativity competencies. The main focus in ER is put on experimentation, debugging, and implementation of real-world projects, corresponding to high-order thinking in Bloom' taxonomy levels. All participants outlined the dual pedagogical role of ER, both as learning objects to support understanding of technological systems and as learning tools that enable interdisciplinary and applied learning, particularly in STEM.

There is a persistent gap between the recognized educational potential of robotics and its effective integration into formal education. Among the main challenges for ER are identified the lack of equipment, insufficient teacher training, lack of time in the formal educational program, the need for flexible instructional resources and lack of institutional support. Further, ER in Bulgaria remains still fragmented and needs more systematic policy support and better alignment with the industry.

## 6. Discussion

The paper provides a coherent analysis of the formulated research questions. In response to RQ1, ER represent interactive learning tools, and facilitate collaborative, experiential and problem-based learning. Concerning RQ2, the findings indicate that ER systematically supports the development of cognitive and future-oriented skills across all levels of Bloom's taxonomy.

RQ3 analysis reveals that ER is still in early stage of development. Educational institutions have to more effectively integrate robotics into curricula by adopting interdisciplinary approaches, strengthening ethical and social dimensions, and aligning robotics with AI literacy goals.

The role of ER goes beyond practical questions and organizational issues, as it sets a more strategic vision for the future of education. For example, Rasa (2025) discusses several perspectives on thinking about "future" and "education". If education is revealed as an instrument "to adapt to the future", young people should raise future-related literacy and readiness. If education serve as a tool "to change the future" young people should practice skills to transform society and address social challenges (e.g. SDGs). Last, if "education is about the future" students have to prepare to envision their own images of the future and to develop skills to put their own visions into practice (Rasa, 2025).

In this respect, integrating robots into education goes beyond basic AI and robotics literacy. New generations need to develop critical thinking skills and capabilities to "transform" and "improve" the future, by understanding and reflecting on the current problems and challenges.

Therefore, the main recommendation for teaching "robot" skills is to integrate ER into main curricula and across disciplines. As GenAI can democratize coding and improve access to knowledge, robots can serve as tools to build a better society for the future.

## 7. Conclusions and future work

The present research outlines the challenges and opportunities for integrating robots in education. On one side, lecturers and institutions often depend on commercial kits and predefined learning scenarios about ER. On the other hand, new generations need to develop future-ready competences related to robotics, in order to recognize them both as "learning objects" and as a "learning tools". While robots and AI technologies are primarily considered as technical subjects or even as "tools for learning", their role remains underestimated within the debates about the future of education and the future of skills. In just a few years, the impact of GenAI tools increased the need for raising AI literacy (Yang et al., 2025). Foundation models for robots are likely to follow, enabling the automation of tasks, workplaces and social roles (Firoozi et al., 2025).

Future work can further investigate specific ER applications, provide comparative analysis of available ER systems and kits, and reveal ER standards for educational institutions.

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## NOTES

1. ChatGPT launched in 2022 marked a milestone for AI and robotics, thus studies before 2023 only partly address current challenges of ER.
2. Anthropic's corporate report, *How University Students Use Claude*. (2025). https://www.anthropic.com/news/anthropic-education-report-how-university-students-use-claude (accessed on 20.01.2026)
3. Ministry of Education and Science, Ordinance No. 15/2025 of 6 October 2025 on Robotics (in BG, МОН, Наредба №15 от 6.10.2025 г. за придобиване на квалификация по професията „Роботика“).
4. Analysis of the Robotics and Mechatronics Industry in the Invest.bg, https://investbg.government.bg/robotics-mechatronics-industry/ (last accessed on 20.01.2026).
5. Roboclub.bg is set up in 2001, as a student's club for robotics in TU Sofia. https://www.roboclub.bg/ Robot club at Burgas State University provides training and summer camps for K-12 students, https://robots.bfu.bg/
6. The PARAi report on ER (2020), https://para.expert/2020/04/28/bulgarskata-obrazovatelna-robotika/
7. The National STEM centre provides funding, training program and equipment for robotics labs in 2000 schools; https://stem.mon.bg/project-methodology-and-stem-resources-description-4/

8. In 2023, MES reported that more than 3600 students took part in clubs on ER and programming (https://www.bta.bg/bg/news/bulgaria/oficial-messages/487554-ministerstvo-na-obrazovanieto-i-naukata-nad-3-600-uchenitsi-ot-tsyalata-strana-)
9. “Robotics for Bulgaria” is launched in 2015, by SAP and WCIF, for teacher training, equipment, and funding for competitions of FIRST LEGO League. (November 2025) https://frgi.bg/novini/stanete-chast-ot-badeshteto-na-tehnologiite-prisaedinete-se-kam-robotika-za-balgariya/
10.Robopartans (https://robopartans.com/) since 2010 in 13 cities, hosts own learning program https://www.fllcasts.com/courses); Tinusaur.bg, has own educational platform for ER since 2013, provides ER kits https://tinusaur.bg/; SparkLab since 2019, specialized in LEGO SPIKE Essential and SPIKE advanced courses https://sparklab.bg/lego-wedo-level-1/, Robo Kids https://www.robokids.academy; Academia Robotics club. https://robotika.bg/; “Nikola Tesla” Academia hosts robotics clubs in Sofia and Varna.

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