

# ***Current Technological Development of Educational Robots for Primary and Secondary Education in the Context of Artificial Intelligence***

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**Abstract.** With the rapid development of artificial intelligence technologies, including machine learning, computer vision, natural language processing, and multimodal large models, educational robots are shifting from single-function electronic teaching aids to personalized learning companions capable of environmental perception, instruction understanding, learning feedback, and project-based support. In primary and secondary education, they must support information technology instruction, scientific inquiry, maker practice, and campus services while also satisfying engineering constraints such as safety, reliability, low cost, maintainability, and scalability. Their technical architecture and mechanical structure therefore need to balance pedagogical value with engineering feasibility. Focusing on policy promotion, curriculum reform, competition practice, and classroom application in China, this paper reviews the development trajectory of educational robots, analyzes five major types - teaching-assistance, programming-development, language-learning, creative-practice, and subject-management robots - and proposes an overall technical framework covering hardware, software, interaction, and application layers. It further identifies a core coordination challenge between multimodal perception integration and the increase of mechanical degrees of freedom: additional sensors raise volume, power consumption, and cost, whereas higher joint freedom increases structural complexity, control difficulty, and safety risk. Future educational robots should move toward lightweight hardware, modular expansion, biomimetic motion, safe interaction, and edge AI collaboration, thereby supporting the popularization of AI education and optimized mechanical structure design.

**Keywords:** educational robots, mechanical structure design, multimodal perception, artificial intelligence education

## **1. Introduction**

The rapid development of artificial intelligence is reshaping educational content, teaching methods, and learning-assessment systems. Deep learning has improved machine vision and speech recognition; natural language processing has strengthened human-robot dialogue and textual

understanding; and multimodal large models have further enabled robots to move from passively executing commands to actively interpreting learning tasks, learning states, and interaction contexts. Against this background, educational robots are no longer merely electronic toys that display program execution results, but are gradually becoming integrated instructional carriers that connect curricular knowledge, engineering practice, data perception, and human-robot interaction [1, 2].

The national emphasis on AI education has provided a policy foundation for the integration of educational robots into primary and secondary schools. The 2016 Thirteenth Five-Year Plan for Educational Informatization proposed building a networked, digital, personalized, and lifelong education system [3]; the State Council's New Generation Artificial Intelligence Development Plan (2017) highlighted intelligent education [4]; the Education Informatization 2.0 Action Plan (2018) emphasized that technologies such as AI and big data would profoundly transform educational paradigms [5]; the Ministry of Education's 2024 initiative on strengthening AI education in primary and secondary schools mandated the construction of systematic curriculum frameworks and the promotion of routine teaching and assessment practices [6]; and the 2026 Action Plan for "AI + Education" jointly issued by the Ministry of Education and four other departments further underscored the comprehensive integration of AI across all educational elements, processes, and scenarios [7].

Existing studies suggest that educational robots can serve as important tools for promoting computational thinking, engineering thinking, STEM learning, and project-based learning. Domestic research mainly reviews the development status of educational robots, common teaching models, and applications in primary and secondary schools, whereas international studies provide systematic evidence from perspectives such as educational potential, open challenges, K-12 robotics knowledge learning, computational-thinking development, and robot-supported STEM education. Collectively, these studies indicate that the routine integration of educational robots into classrooms depends not only on individual algorithmic capabilities, but also on the coordination of mechanical structure, curriculum resources, teacher support, and data governance.

Unlike industrial robots, which emphasize high precision, high speed, and continuous operation, educational robots for primary and secondary schools place greater emphasis on safety and reliability, low-cost popularization, engaging interaction, structural reconfigurability, and curriculum adaptability. As AI and multimodal technologies continue to enter classrooms, educational robots serve both as practical objects through which students learn programming logic, control principles, sensor applications, and basic AI algorithms, and as important auxiliary tools for teachers conducting STEM education, maker activities, language learning, and scientific inquiry. This paper studies educational robots for primary and secondary schools, focusing on conceptual classification, development and application in China, overall technical architecture, and mechanical structure design, thereby laying a foundation for subsequent analysis of robot chassis, joints, sensor layout, and human-robot interaction structures.

## 2. Concepts and classification of educational robots

### 2.1. Concept of educational robot

Educational robots are intelligent systems that integrate artificial intelligence, sensor technology, motion control, mechanical structure design, and educational-resource design. They mainly serve scenarios such as classroom teaching, project practice, language learning, vocational training, and special education. In terms of functional positioning, an educational robot is not only a teaching tool

but may also act as a teaching assistant, learning partner, training platform, or campus service terminal [8-10].

In basic education, educational robots can support homework tutoring, introductory programming, scientific experiments, language dialogue, and maker practice. In higher education and vocational training, they are often used as platforms for AI algorithm debugging, embedded-system development, and robot-control experiments. In special education, robots equipped with speech, facial-expression, and motion-feedback capabilities can assist with social training, emotion recognition, and behavioral intervention.

From the perspectives of market form and teaching mode, educational robots generally include two directions: robotics education and educational service robots. Robotics education emphasizes the cultivation of students' computational thinking, engineering thinking, and innovation ability through modular kits, curricular resources, and project tasks. Educational service robots, by contrast, are closer to a subcategory of service robots applied in educational settings. They usually have relatively fixed mechanical structures and appearances, and provide assistance for tasks such as STEAM education, language learning, campus guidance, homework tutoring, and learning support for special populations [11-13].

From a system-composition perspective, educational robots for primary and secondary schools mainly consist of the mechanical body, drive and actuation system, perception system, computation and control system, human-robot interaction system, power supply and safety-protection system, and curriculum-resource and data-evaluation system. The mechanical body determines form and load capacity; the drive and actuation system determines movement capability; the perception system collects environmental and learning-behavior data; the computation and control system executes programs and AI inference; the human-robot interaction system provides speech, screen, motion, and expression feedback; the power supply and safety-protection system determines stability in classroom use; and the curriculum-resource and data-evaluation system directly affects the implementation of teaching objectives.

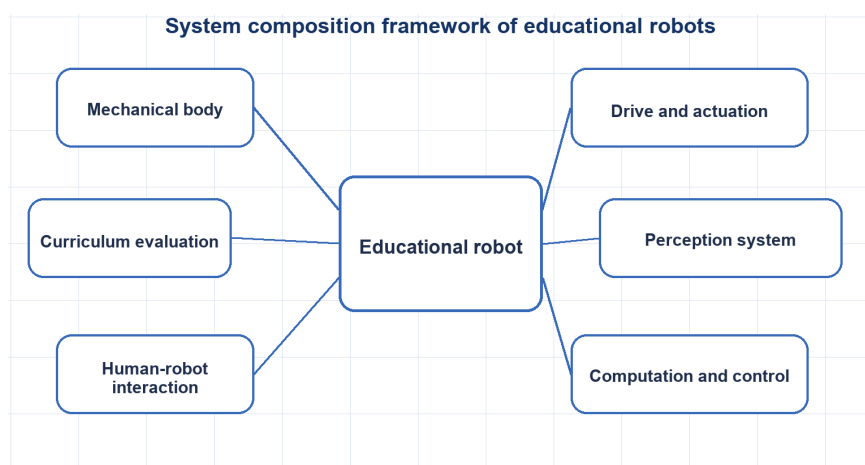


Figure 1. System architecture of educational robots

## 2.2. Classification of educational robots

According to classroom tasks and product functions in primary and secondary schools, educational robots can be classified into five categories: teaching-assistance, programming-development,

language-learning, creative-practice, and subject-management robots. Different types vary in appearance, curriculum entry points, and technological emphasis.

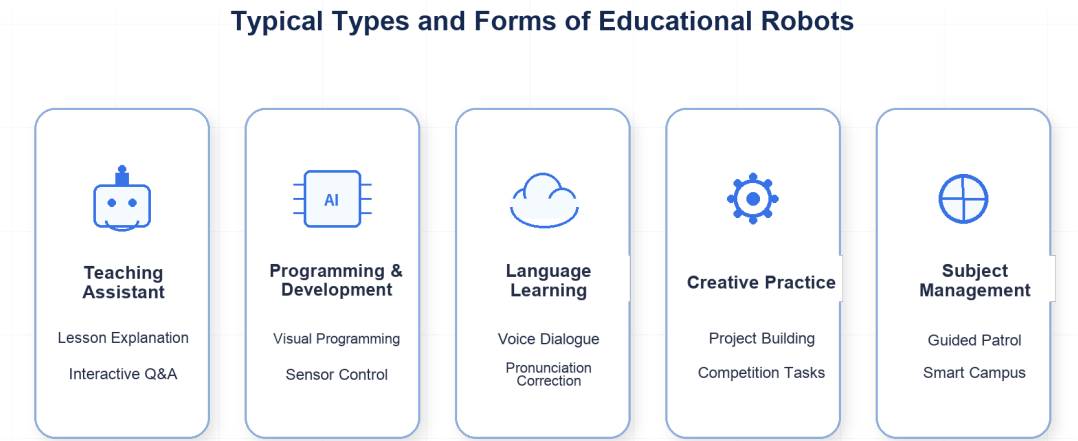


Figure 2. Representative categories and structural schematics of educational robots

### 2.2.1. Teaching-assistance educational robots

Teaching-assistance robots primarily serve as teacher assistants for classroom explanation, experimental demonstration, and interactive question answering. They usually feature anthropomorphic appearances, speech interaction, screen display, and motion feedback.

### 2.2.2. Programming-development educational robots

Programming-development robots are the most widely used type in primary and secondary STEAM education. Their core objective is to cultivate students' computational thinking, logical reasoning, sensor application, and hands-on practice abilities. Through graphical programming, Python, or C++, students can control robots to complete line tracking, obstacle avoidance, grasping, recognition, and autonomous navigation tasks, thereby understanding the relationships among mechanical structures, sensor signals, control algorithms, and program logic. Representative products include LEGO Education EV3, DJI RoboMaster TT, and Makeblock mBot [14, 13].

### 2.2.3. Language-learning educational robots

Language-learning robots are based on speech recognition, natural language processing, and dialogue-generation technologies, and they mainly address students' barriers to speaking and the problem of low-frequency language practice. They can provide pronunciation correction, scenario-based dialogue, picture-book reading, picture-based speaking, and graded oral training, while adjusting topic difficulty according to students' proficiency levels. Representative products include NetEase Youdao Hi Echo and UBTECH Wukong. Compared with traditional speech-learning software, physical robots enhance companionship through expressions, actions, and spatial presence, but privacy protection and content safety must be given particular attention.

#### **2.2.4. Creative-practice educational robots**

Creative-practice robots emphasize learning by doing and are often combined with robotics competitions, maker activities, and project-based learning. Students carry out structural design, program development, and task debugging around themes such as environmental protection, future cities, intelligent transportation, and campus services, and complete football matches, material handling, automatic inspection, or integrated challenge tasks through teamwork. Representative platforms include VEX Robotics Competition kits, MakeX Robotics Challenge kits, and FIRST LEGO League engineering challenge kits. This type of robot can enhance comprehensive practical ability, but it also places higher demands on school equipment investment, teacher guidance, and safety management.

#### **2.2.5. Subject-management educational robots**

Subject-management robots are closer to intelligent campus service terminals and are mainly used to improve school management efficiency and public service quality. They can undertake tasks such as security patrols, library inventory, route guidance, school-history museum explanations, front-desk reception, and standardized consultation on campus, and they usually possess SLAM mapping, autonomous navigation, obstacle avoidance, and speech question-answering capabilities. Representative products include Xiaoben Intelligence and Pangolin robots. Although these robots are relatively less directly connected with teaching activities, they help schools build smart campuses and provide students with authentic observation scenarios for robot applications.

### **3. Development and application of educational robots in China**

#### **3.1. Development history of educational robots**

The development of educational robots in China is not the natural expansion of a single product line, but a process jointly promoted by educational informatization policies, artificial intelligence strategies, curriculum reform, STEM and maker education, and various robotics competitions. Overall, it has undergone a transition from interest clubs and competition training to classroom teaching, from single programming kits to integrated AI capabilities, and from extracurricular training orientation to in-school curriculum system construction [15, 16].

Around 2016, educational robots mainly appeared in science and technology clubs, maker spaces, and competition activities. The equipment purchased by schools was mostly assembly kits and programming-control kits, and the teaching objectives focused on mechanical construction, basic control, and graphical programming. The 2016 Thirteenth Five-Year Plan for Educational Informatization proposed promoting the construction of networked, digital, personalized, and lifelong education systems, providing an informatization foundation for intelligent educational equipment to enter schools [3].

In 2017, the State Council issued the New Generation Artificial Intelligence Development Plan, which clearly proposed the development of intelligent education and incorporated intelligent technology application, smart campus construction, and interdisciplinary talent cultivation into the national strategic vision [4]. Under this influence, educational robots began to shift from pure competition equipment to carriers of AI education, and functions such as visual recognition, speech recognition, intelligent question answering, and data collection were gradually incorporated into product design.

The Education Informatization 2.0 Action Plan in 2018 further emphasized the impact of emerging technologies such as artificial intelligence and big data on educational concepts, educational ecosystems, and talent demand, pushing schools to move from equipment procurement toward curriculum integration and teaching-model innovation [5]. Thereafter, educational robots were implemented more rapidly in information technology, science, comprehensive practical activities, and maker courses, while product forms expanded from single wheeled vehicles to robotic arms, humanoid robots, drones, and composite teaching platforms.

The 2022 Information Technology Curriculum Standards for Compulsory Education strengthened content related to algorithms, data, the Internet of Things, and artificial intelligence, thereby giving educational robots clearer curriculum entry points. In 2024, the Ministry of Education deployed efforts to strengthen AI education in primary and secondary schools, proposing the construction of systematic curriculum frameworks, routine teaching and evaluation, and pilot practices by localities and schools [6]. The 2026 AI + Education Action Plan further emphasized the integration of intelligent technologies across all educational scenarios, so educational robots have gradually shifted from optional maker equipment to important terminals supporting the popularization of AI education [7].

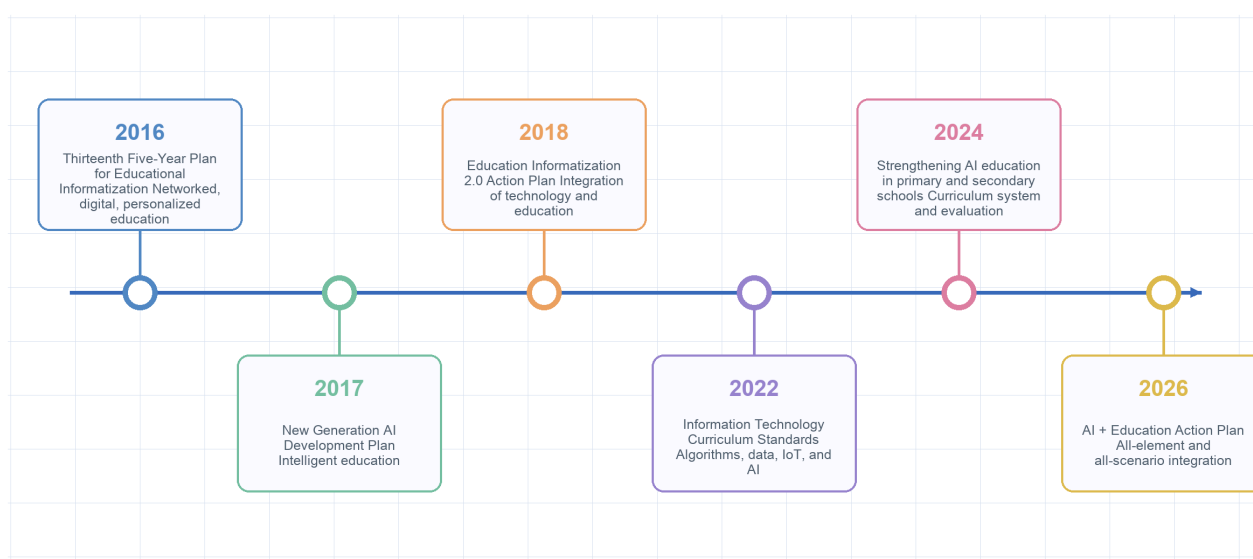


Figure 3. Evolution of policies related to AI education and educational robots in China

### 3.2. Application status of educational robots

At present, the application of educational robots in primary and secondary school campuses has formed a pattern in which classroom teaching, after-school services, competition practice, and campus management operate in parallel. According to industry research institutions' observations of China's educational-robot industry, the market size of educational robots in China reached approximately RMB 4.4 billion in 2024. Higher education and vocational education remained the main application fields, while primary and secondary school scenarios were more concentrated in STEAM education, maker practice, and introductory AI courses [17]. This indicates that educational robots already have a certain market foundation, but their routine application in primary and secondary schools is still in the expansion stage.

In information technology classrooms, robots are often used for program design, sensor data acquisition, Internet of Things control, and AI experience. For example, students understand conditional judgments and loop structures through line-tracking vehicles, sensor input and actuator output through ultrasonic obstacle avoidance, and the basic process of machine vision through cameras that identify colors or QR codes. In science classrooms, robots can undertake tasks such as automatic distance measurement, data collection, motion-trajectory recording, and experimental demonstration, making abstract physical, engineering, and data concepts observable and operable.

In after-school services and student clubs, educational robots more often undertake maker projects and competition-training tasks. Students design solutions around themes such as campus inspection, intelligent waste sorting, automatic handling, low-carbon cities, and accessibility services, and complete structural construction, program debugging, presentation, and defense. In language learning and special education scenarios, robots can provide low-pressure dialogue practice, emotional companionship, and social training, helping students obtain more stable interaction partners and higher-frequency practice opportunities.

The advantages of educational robots in empowering smart campus education have gradually emerged, mainly in enhancing learning interest, strengthening practical experience, promoting interdisciplinary integration, and supporting process-based evaluation. However, shortcomings remain during large-scale implementation, including large differences in equipment utilization across schools, insufficient systematic training for front-line teachers, inadequate alignment between curriculum objectives and equipment-configuration standards, products that emphasize display more than teaching, and data privacy and security norms that still require improvement [18, 19, 1].

Table 1. Main application scenarios of educational robots in primary and secondary schools

| Application scenario             | Main tasks                                                          | Typical devices or systems                                    | Teaching value                                              | Main problems                                                     |
|----------------------------------|---------------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------------|-------------------------------------------------------------------|
| Information technology classroom | Programming control<br>Sensor experiments<br>AI experience          | Wheeled vehicle<br>Vision module<br>Main control board        | Reduces the difficulty of understanding abstract algorithms | Limited class hours<br>Insufficient teacher training              |
| Science inquiry classroom        | Data collection<br>Motion observation<br>Experimental demonstration | Distance sensor<br>Robotic arm<br>Mobile platform             | Connects scientific concepts with engineering practice      | Insufficient alignment with subject textbooks                     |
| After-school services and clubs  | Maker projects<br>Teamwork<br>Presentation and defense              | Modular kits<br>Open-source hardware<br>Competition platforms | Cultivates problem-solving and innovation abilities         | High equipment maintenance and consumable costs                   |
| Robotics competitions            | Task challenges<br>Structural optimization<br>Program debugging     | VEX, MakeX, FLL, and other kits                               | Strengthens comprehensive practice and teamwork             | Participation can easily be limited to a small number of students |
| Campus services                  | Guided tours<br>Library inventory<br>Security patrols               | Service robots<br>SLAM navigation systems                     | Expands authentic application scenarios                     | High requirements for investment cost and management norms        |

#### 4. Overall technical architecture for primary and secondary schools

Educational robots for primary and secondary schools are not merely hardware devices, but teaching systems composed of mechanical structures, electronics and electrical systems, artificial intelligence algorithms, teaching resources, and learning evaluation. Their overall technical architecture can be

divided into four levels: the hardware layer, software layer, interaction layer, and application layer. The four-layer structure supports itself mutually: the hardware layer provides the foundation for motion and perception, the software layer provides program operation and AI inference capabilities, the interaction layer establishes natural communication channels between humans and machines, and the application layer transforms robot capabilities into specific curriculum tasks and learning evaluation [12-14].

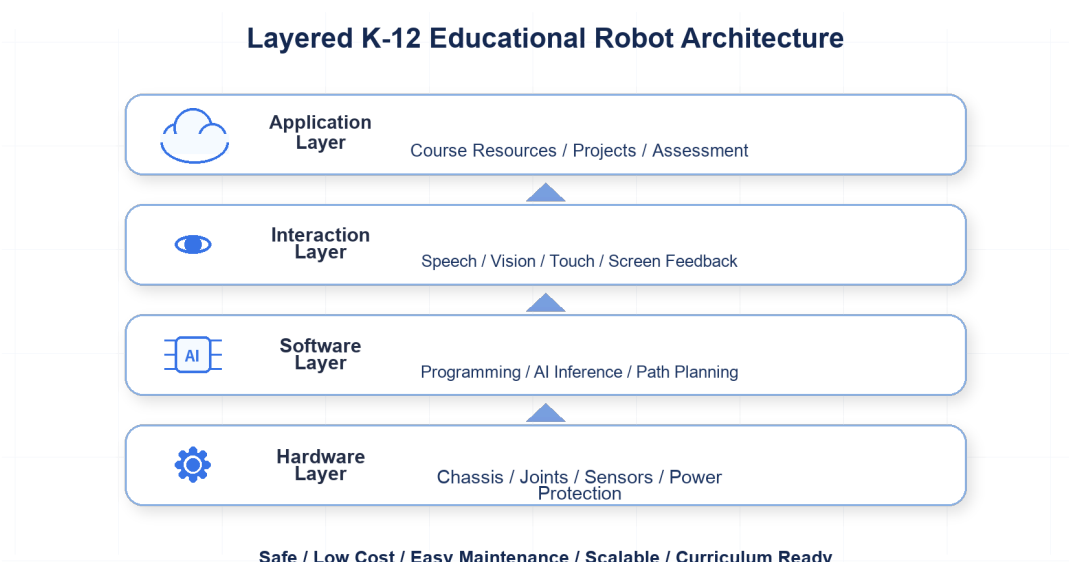


Figure 4. Layered technical architecture for educational robots in primary and secondary schools

The hardware layer is the physical carrier and safety foundation of an educational robot system. It mainly includes mobile chassis, movable joints, drive servos, motors, robotic arms, sensors, main control units, communication modules, power-supply modules, and protective shells. For primary and secondary classrooms, hardware-layer design should prioritize collision prevention, pinch prevention, low noise, lightweight construction, and easy maintenance. Wheeled chassis are suitable for programming introduction and campus inspection; tracked structures are suitable for complex ground and obstacle-crossing demonstrations; humanoid or biomimetic structures are suitable for language interaction and action performance; and robotic arms are suitable for grasping, sorting, and automated experiments.

The software layer is the core hub for teaching-function control and AI capability empowerment. It mainly includes graphical programming environments, Python or C++ development interfaces, edge AI inference modules, visual recognition algorithms, speech recognition and synthesis modules, path-planning algorithms, learning-process data recording systems, and device-management systems. For primary and secondary school students, the software layer needs to lower the entry threshold while maintaining interpretability. Graphical programming helps lower-grade students understand sequence, loops, and judgment; text-based programming is suitable for higher-grade students to understand variables, functions, and algorithms in depth; and edge AI modules can support experiential activities such as image classification, speech interaction, and pose recognition.

The interaction layer is the direct interface for information exchange between robots, teachers, and students. It mainly covers speech interaction, machine vision, touch perception, screen display, light prompts, expression feedback, and motion feedback. Multimodal interaction can increase students' participation, but it also increases the number of cameras, microphones, and sensors,

thereby bringing pressure related to power consumption, cost, and privacy protection. Therefore, educational robots need to adopt mechanisms such as minimum necessary data collection, local-first processing, data desensitization, and permission control to ensure that classroom applications are safe and controllable [1].

The application layer is the final carrier through which the teaching value of educational robots is implemented. It mainly includes curriculum resource libraries, project-based learning tasks, experiment guides, competition task packages, learning-evaluation rubrics, and teacher management platforms. The application layer should be aligned with primary and secondary curriculum standards and students' cognitive characteristics at different grade levels, so that robots do not merely demonstrate technological effects but serve specific learning objectives. For example, lower grades can conduct introductory activities around graphical programming and simple sensors, while middle and upper grades can gradually introduce data collection, machine vision, path planning, mechanical structure optimization, and AI model experience.

The subsequent research in this paper focuses on the mechanical structure design of educational robots for primary and secondary schools, with emphasis on mobile chassis, robotic arms, joint degrees of freedom, servo motors, sensor layout, and shell safety structures. The core issue of concern is the collaborative optimization between multimodal perception systems and mechanical degrees of freedom. On the one hand, robots need to integrate sensors such as cameras, microphones, touch, distance, inertial measurement, and force feedback to support more natural AI interaction. On the other hand, excessive sensors and higher degrees of freedom increase structural weight, control complexity, maintenance costs, and safety risks. Therefore, reasonable mechanical structure design should form a balance among teaching function, safety, cost, maintainability, and scalability.

## 5. Mechanical structure design analysis of educational robots

Mechanical structure design is a foundational element determining whether educational robots can truly enter primary and secondary classrooms. For educational robots, mechanical structures not only provide support, motion, and protection, but also directly affect whether students can observe structural principles, assemble and disassemble components, understand transmission relationships, and complete project practice. Therefore, educational robots for primary and secondary schools should not simply pursue high degrees of freedom, highly realistic appearances, or complex movements; rather, they should balance classroom safety, low-cost popularization, easy assembly and maintenance, durability, modular expansion, and pedagogical visibility [10, 11, 13].

The core of educational robot mechanical design mainly includes transmission mechanisms, drive and actuation, appearance design, base design, humanoid and biomimetic structures, embodied interaction structures, and modular interfaces. Transmission mechanisms usually consist of gears, linkages, synchronous belts, lead screws, and quick-release connectors, which convert motor output into stable, observable, and explainable mechanical motion. Drive and actuation often use servos, DC geared motors, stepper motors, and closed-loop motors with encoders, corresponding respectively to teaching needs such as low-cost posture control, mobile chassis driving, precise positioning, and feedback control.

Appearance design must consider both affinity and safety, avoiding sharp edges and pinch spaces. Base design determines movement stability and sensor-layout conditions; humanoid design emphasizes the coordination of expressions, head and neck, upper limbs, and speech interaction; and embodied design further emphasizes how robots interact with the environment through bodily

actions, helping students understand that artificial intelligence is not an isolated algorithm but a system composed of perception, decision-making, and action [2].

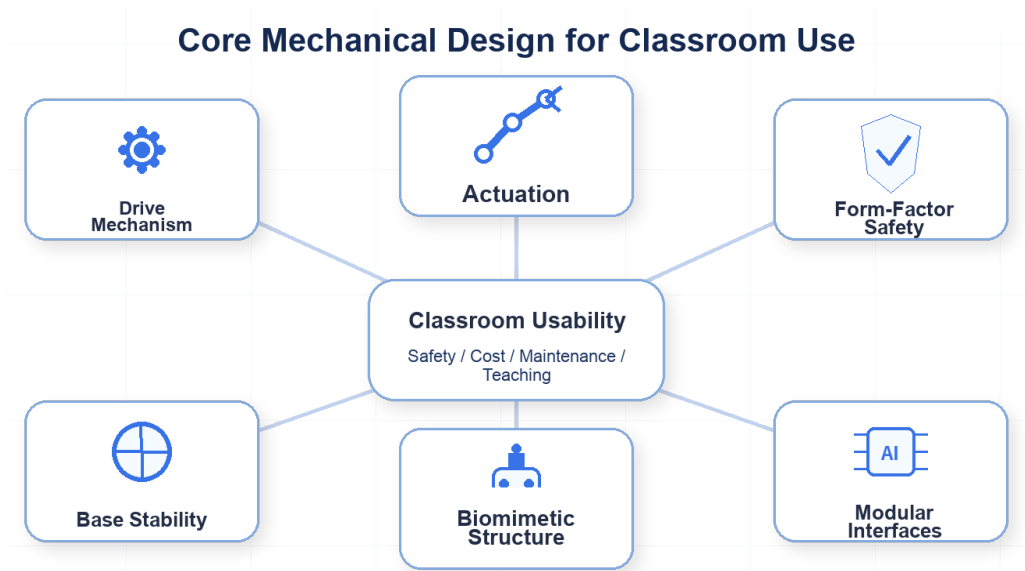


Figure 5. Core mechanical structure design for classroom implementation

There is an obvious relationship between different mechanical forms and classroom tasks. Modular robots emphasize buildability and reconfigurability; humanoid robots emphasize emotional and language interaction; desktop robotic arms emphasize automation control and spatial motion; and wheeled mobile robots emphasize path planning and sensor fusion. Figure 6 provides a schematic presentation of four common mechanical forms.

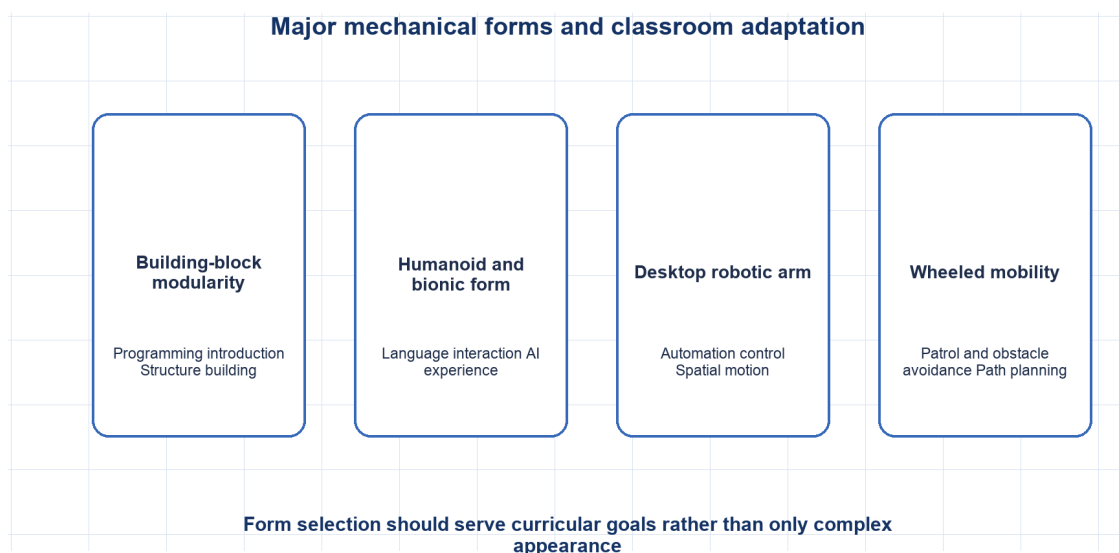


Figure 6. Major mechanical forms and classroom adaptation

### **5.1. Building-block and modular robots**

Building-block and modular robots are among the most common teaching forms in primary and secondary schools. They usually use standard hole positions, standard connectors, and reusable electronic modules, enabling students to recombine chassis, sensors, robotic arms, and shell structures according to tasks. These robots are suitable for programming introduction, engineering design, STEM projects, and robotics competitions, and they allow students to directly observe the relationships among structural strength, center of gravity, transmission efficiency, and program control during construction. Their main limitations are that connectors are prone to wear after long-term use, structural rigidity and load capacity are limited, and loosening or deformation can easily occur in high-intensity competitions or complex action tasks.

### **5.2. Humanoid and biomimetic robots**

Humanoid and biomimetic robots emphasize affinity, emotional interaction, and action expression, and they usually have functions such as head and neck rotation, upper-limb swinging, expression screens, speech interaction, and simple gait control. In language learning, companionship interaction, AI experience classes, and special education scenarios, humanoid forms can reduce the psychological distance between students and machines and enhance classroom participation. At the same time, these structures place higher requirements on degree-of-freedom configuration, servo lifespan, center-of-gravity stability, and shell safety, and their cost and maintenance difficulty are significantly higher than those of modular robots. Therefore, in primary and secondary school scenarios, humanoid robots are more suitable as carriers for interaction demonstration, language practice, and AI experience, rather than making complex gait or difficult movements the main objective of popularized application.

### **5.3. Desktop robotic arms**

Desktop robotic arms usually adopt serial joints, SCARA configurations, or lightweight multi-joint structures, and their end effectors can be replaced with grippers, suction cups, pen holders, and sensor modules. They are suitable for teaching automation control, Industry 4.0 introduction, physics experiments, coordinate transformation, and end-effector design. Students can use robotic arms to understand joint angles, end trajectories, kinematic constraints, and closed-loop control concepts. Their limitation is that clear safety boundaries must be established, gripper force, movement speed, and end accuracy must be calibrated, and teachers also need certain device-debugging capabilities.

### **5.4. Wheeled mobile robots**

Wheeled mobile robots use differential wheels, mecanum wheels, omnidirectional wheels, or tracked chassis as their main structures, offering advantages such as stable movement, relatively low cost, and intuitive task scenarios. They are commonly used in teaching projects such as line tracking, obstacle avoidance, path planning, map exploration, and campus guidance, connecting sensors, control algorithms, and real environments. Wheeled structures are sensitive to ground flatness, lighting conditions, and site boundaries, and their biomimetic expressiveness is weak. However, because they are stable, reliable, easy to maintain, and supported by abundant curriculum resources, they remain the most widely applicable form in primary and secondary AI and robotics courses.

### 5.5. Structural safety and maintenance points in classroom environments

Overall, mechanical structure design for classrooms should follow the principle of moderate complexity. For lower-grade students, modular robots with clear structures, large components, and low assembly difficulty should be prioritized. For junior and senior secondary levels, robotic arms, closed-loop motors, vision modules, and programmable chassis can be gradually introduced, allowing students to move from construction and control toward system integration and problem solving. As the demand for AI perception and precise control increases, closed-loop motors with encoders, torque limitation, flexible coverings, emergency stop switches, and pinch-prevention structures will become increasingly important, and mechanical design will also need to move beyond simply carrying hardware toward supporting perception quality, interaction experience, and learning evaluation.

In daily operation and maintenance, schools are more suited to a configuration approach based on a unified basic chassis, replaceable functional modules, and standardized consumables. The chassis and main control board should remain stable, while sensors, end effectors, shell stickers, and curriculum task packages can be upgraded gradually by grade level. Key components should adopt color coding, foolproof orientation design, and rapid diagnostic design to reduce teachers' pressure in classroom assembly and troubleshooting. Assembly and disassembly areas open to students should be isolated from batteries, high-speed rotating components, and high-temperature elements, which both ensures safety and helps transform structural design principles into education on engineering ethics and safety norms.

### 6. Integration of AI technologies in interaction and teaching

AI technology is transforming educational robots from tools that execute programs into teaching partners capable of perceiving the environment, understanding instructions, and feeding back the learning process. In primary and secondary classrooms, the AI capabilities most suitable for implementation can be summarized into five categories: visual recognition, speech interaction, large-language-model assistance, learning analytics, and embodied action. These capabilities should not be stacked in isolation, but should form a closed loop of perception, cognition, feedback, and evaluation around specific tasks [1, 2].

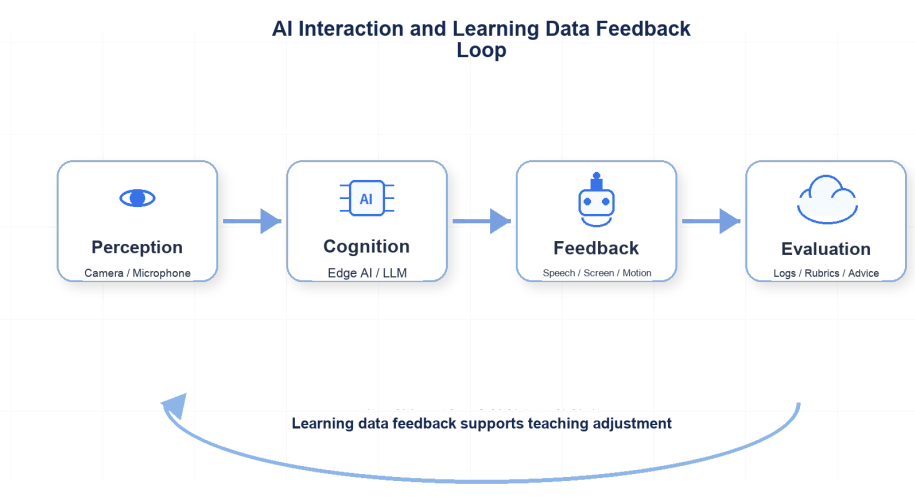


Figure 7. AI interaction integration and learning data feedback

### 6.1. Major AI capabilities and classroom roles

Computer vision is suitable for color classification, line tracking, waste sorting, pose imitation, and experiment recording, turning abstract algorithms into observable results. Speech and natural language processing are suitable for question answering, reading aloud, and pronunciation correction, but they are affected by classroom noise. Large language models can assist with project prompts, knowledge explanation, and teacher lesson preparation, but they require content review, age adaptation, and control of knowledge boundaries. Learning analytics can record task completion time, error types, and debugging processes to help teachers conduct process-based evaluation. Path planning and embodied intelligence are suitable for maze obstacle avoidance, robotic-arm grasping, and strategy competitions, helping students understand the interaction between AI and real environments [14, 19, 1].

### 6.2. Multimodal perception and the human-machine interaction loop

AI integration in classroom educational robots should move from single-point functions toward closed-loop tasks. Taking a waste-sorting project as an example, the robot first identifies the object category through a camera, determines the grasping position through a distance sensor, then generates an action strategy through a small model or rule base, finally executes the task through a robotic arm or mobile chassis, and records recognition errors, grasping failures, and debugging attempts in a learning-evaluation table. Such a closed loop connects seeing, judging, acting, and reflecting, enabling students to understand that AI is not a stand-alone algorithm demonstration, but a system jointly composed of perception, cognition, and action.

Multimodal interaction also needs to consider complex classroom conditions such as noise, lighting changes, and multiple users operating simultaneously. Cameras should use fixed viewing angles or adjustable brackets as much as possible to avoid being blocked by robotic arms or students' hands. Microphone openings should avoid noise sources such as motors and fans, with microphone arrays or push-to-wake mechanisms added when necessary. Touch, IMU, and force-feedback sensors should avoid areas with strong vibration and high-current wiring. Only when mechanical structures and AI algorithms are designed together can recognition accuracy and interaction stability avoid rapid decline in real classrooms.

### 6.3. Edge-cloud collaboration and data security in AI

School scenarios are more suitable for a hybrid solution combining local small models, rule bases, and cloud-based large models: routine recognition, path planning, speech wake-up, and learning-data recording should be completed locally as much as possible, while high-quality dialogue, complex explanations, and lesson-preparation support can call cloud services as needed. This approach balances response speed, classroom continuity under unstable network conditions, and requirements for the protection of minors' data. For lower-grade students, robots should reduce open-ended dialogue and limit output to teacher-reviewed curriculum resources and task prompts. For higher-grade projects, model-parameter adjustment, prompt design, and data annotation can be gradually opened so that students understand the boundaries and responsibilities of AI systems [1].

In terms of data governance, educational robots should adhere to minimum necessary collection, local-first processing, desensitized storage, explicit authorization, and traceable management. Cameras and microphones should not continuously collect data during non-teaching tasks, and students' names, portraits, voices, and behavioral logs need hierarchical management. Teacher

management terminals should be able to display data purposes, retention periods, and deletion mechanisms. Schools should also avoid equating robot evaluation results directly with students' comprehensive abilities, preventing technical evaluation from replacing teachers' professional judgment and emotional support.

#### **6.4. Teaching evaluation and teacher support**

The teaching value of AI integration is also reflected in process-based evaluation and teacher support. Traditional robotics courses often focus only on whether the final task succeeds, whereas AI-enabled robots can record debugging attempts, code modification paths, sensor threshold changes, cooperation division, and causes of failure, making it easier for teachers to evaluate students' problem analysis, iterative optimization, and teamwork abilities. The teacher-facing backend should not present only scores; it should also provide task-completion curves, common error prompts, classroom grouping suggestions, and next-step teaching resources, so that robots truly become auxiliary tools for teachers' instructional decision-making.

#### **6.5. Key points in integrated design**

Whether AI capabilities can function stably depends on the coordination between mechanical structures and software systems. Cameras need stable viewing angles, microphones require reasonable openings and noise-reduction structures, and sensors must avoid vibration and electromagnetic interference. In software, modular interfaces should be adopted to divide visual recognition, speech interaction, motion control, log recording, and teacher management into replaceable units, making it easier for schools to upgrade curricula without replacing the entire machine. Pedagogically, AI capabilities should be embedded into real tasks rather than separately demonstrating effects such as being able to chat or recognize objects, thereby forming classroom solutions that are explainable, evaluable, and reusable.

#### **7. Challenges and bottlenecks**

The current problems of educational robots in primary and secondary schools are not caused by a single technological deficiency, but by the lack of stable coordination among cost, structure, safety, curriculum, teachers, and data governance. If high-degree-of-freedom appearance or large-model dialogue is pursued while classroom usability is ignored, robots are likely to remain display devices and will struggle to enter daily teaching over the long term.

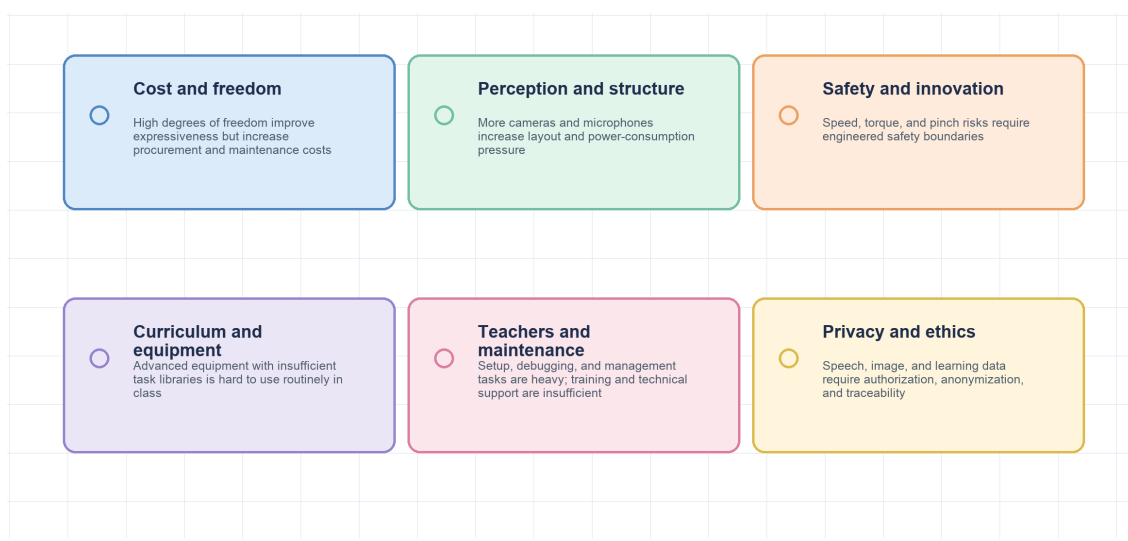


Figure 8. Main challenge matrix for educational robots in primary and secondary schools

### 7.1. Balance between structural cost and safety

High-degree-of-freedom humanoid structures can provide richer action expression, but they increase servo costs, control difficulty, maintenance expenses, and failure risks. Ordinary schools need stable, shareable, and easy-to-maintain equipment more urgently. Therefore, basic classrooms should mainly use wheeled chassis and modular structures, while advanced courses can introduce robotic arms or biomimetic joints. At the same time, speed limits, low-voltage power supply, flexible coverings, torque limits, emergency stop switches, and pinch-prevention structures should become basic configurations, and safety design itself can also be transformed into engineering ethics teaching content.

### 7.2. Insufficient curriculum, teachers, and data governance

Some schools are equipped with advanced devices, but lack project libraries, task sheets, and evaluation rubrics corresponding to curriculum standards, resulting in use that is concentrated in competitions or open classes. Teachers also need to handle mechanical construction, program debugging, sensor principles, and AI applications at the same time, and insufficient training and technical support will reduce classroom quality. On the other hand, speech, image, and learning-process data involve minors' privacy, so minimum necessary collection, local-first processing, desensitized storage, explicit authorization, and traceable management should be maintained to avoid replacing teachers' emotional care and value judgment with robots [1].

## 8. Future development trends and prospects

In the future, educational robots for primary and secondary schools will develop from single-machine hardware into integrated systems combining mechanical structures, AI modules, curriculum resources, and teacher support. The focus of development should not merely be on becoming more humanlike or more intelligent, but on classroom usability, teachability for teachers, learnability for students, and maintainability for schools.

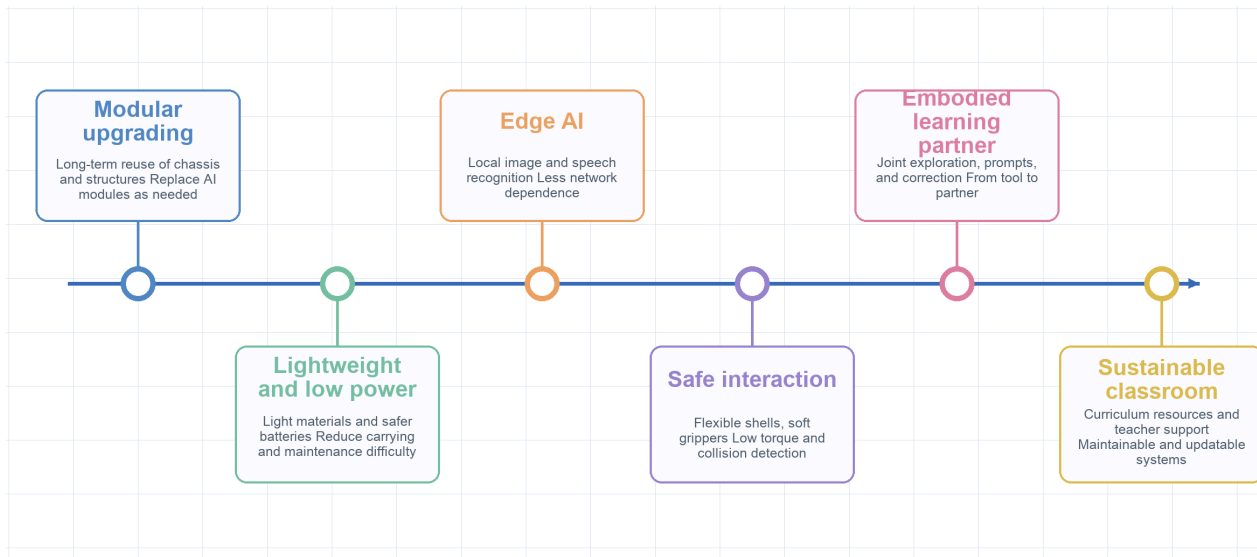


Figure 9. Future development roadmap for educational robots in primary and secondary schools

### 8.1. Modular lightweight design and edge AI

The decoupling of software and hardware will become an important direction: chassis, structural components, and actuators should maintain longer service cycles, while vision, speech, computing, and software modules can be upgraded according to curriculum needs. Lightweight materials, low-power chips, and safer batteries can help reduce the difficulty of carrying, maintenance, and classroom organization. Edge AI can complete image classification, speech recognition, gesture recognition, and simple learning analytics locally, reducing network dependence and data-upload risks, while cloud-based large models can be used for more complex explanations, dialogue, and lesson-preparation support.

### 8.2. Safe interaction and transformation into learning partners

Flexible shells, soft grippers, collision detection, and low-torque joints will improve the safety of physical interaction, making robots more suitable for younger students and special education scenarios. With the development of embodied intelligence, educational robots will no longer simply execute preset instructions, but will become learning partners that explore, prompt, correct, and reflect with students in project tasks [20]. Truly valuable products need to integrate mechanical bodies, perception systems, cognitive models, curriculum tasks, and learning evaluation [2].

## 9. Conclusion

Educational robots for primary and secondary schools are important carriers for implementing artificial intelligence education. Their value lies not only in teaching programming, but also in integrating algorithms, structures, sensing, electronic control, and real problem solving into classrooms. On the basis of concepts, classification, development history, application status, and overall technical architecture of educational robots, this paper further analyzes mechanical structure design, AI interaction integration, practical bottlenecks, and future trends. The review shows that current technical cores include multimodal perception, edge AI, natural language interaction,

learning analytics, and the perception-cognition-action loop, while the design cores are safety, low cost, reconfigurability, durability, and pedagogical adaptation.

Future research and product development for educational robots should avoid treating high degrees of freedom, high realism, or large-model capabilities as the only indicators, and should instead establish evaluation standards around real classroom needs. For schools, educational robots should be portable, maintainable, updatable, and explainable. For teachers, they should serve curriculum objectives and classroom organization. For students, they should support hands-on practice, problem inquiry, teamwork, and innovative expression. Only when mechanical structures, AI capabilities, curriculum resources, and teacher support form synergy can educational robots transform from display-oriented equipment into routine and sustainable carriers of AI education.

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