Research on the Curriculum System for Cultivating On-site Engineers in Industrial Robot Technology Specialty

Shou Heng, Dai Junliang, Ling Xu

[**Abstract**] Aiming at the requirements for cultivating on-site engineers in the higher vocational industrial robot technology specialty, this paper analyzes the connotations of "proficient in operation, knowledgeable in technology, capable of management, good at collaboration, and innovative" that industrial robot on-site engineers need to possess, as well as the specific requirements for adapting to digital and intelligent vocational scenarios. On this basis, the construction concepts of the curriculum system are proposed, including integration of work and study, competency-based orientation, and digital-intelligent guidance. The construction ideas are clarified, including school-enterprise collaboration, hierarchical progression, modular design, and digital-intelligent integration. The modular curriculum content is planned, and a curriculum system that meets industrial needs is constructed to enhance students' vocational adaptability and cultivate high-quality on-site engineers for the industrial robot field.

[**Key words**] industrial robot; on-site engineer; curriculum system

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1 Introduction

In October 2022, the Ministry of Education and four other government departments jointly issued the *Notice on Implementing the Special Initiative for Cultivating On-site Engineers in Vocational Education*. The document highlights the need to target digitalized and intelligent vocational scenarios in key sectors, including advanced manufacturing and strategic emerging industries, and calls for multi-stakeholder collaboration to cultivate at least 200,000 on-site engineers by 2025. These professionals are expected to embody the spirit of craftsmanship, and be proficient in operation, knowledgeable in technology, capable of management, good at collaboration, and innovative.

It also proposes that the Chinese-characteristic apprenticeship system shall serve as the primary training model, featuring school-enterprise joint cultivation. Enterprises are to set up on-site engineer apprenticeship posts and define the corresponding knowledge, capability, and quality requirements for these posts. Schools and enterprises shall jointly build the specialized curriculum system and develop core courses, organize teaching flexibly based on authentic production tasks, and reinforce the cultivation of practical competence through work-study alternation.

Consequently, talent cultivation in the higher vocational Industrial Robot Technology specialty is closely aligned with the digitalized and intelligent professional settings in these key sectors. Against this backdrop, it is imperative to conduct research on the curriculum system for this specialty to enhance students' professional adaptability and facilitate the cultivation of on-site engineers in this discipline.

2 Connotation of industrial robot on-site engineers

The overarching connotation of on-site engineer lies in embodying the competencies of "proficient in operation, knowledgeable in technology, capable of management, good at collaboration, and innovative", thereby enabling adaptation to digital and intelligent vocational scenarios. Within the domain of industrial robotics, these attributes acquire specific meanings: (1) Proficient in operation: Possessing the ability to perform mechanical assembly of robot bodies and peripheral systems, electrical wiring, programming and debugging, equipment operation, as well as maintenance and repair. (2) Knowledgeable in technology: Demonstrating a thorough understanding of the production workflows and process parameters of the products being serviced; capable of translating product process flows into production line logic and converting process parameters into operational parameters for industrial robots. (3) Capable of management: Applying systems engineering and lean production principles to coordinate the allocation of production line resources, workforce scheduling, and material logistics, thereby ensuring efficient production flow. (4) Good at collaboration: Working closely with personnel across diverse disciplinary backgrounds—whether communicating improvement directions with R&D teams, cooperating with sales teams to meet customer demands, or coordinating with planning and scheduling teams to enhance production efficiency. (5) Innovative: Daring to challenge conventional thinking amidst evolving technological landscapes, exploring novel applications for robots in emerging fields, and refining operational methods and process workflows.

In digital vocational scenarios, on-site engineers in the industrial robotics domain are expected to master data acquisition and analysis techniques, so as to optimize robot performance and formulate maintenance plans through the analysis of operational data. They should also be familiar with digital twin systems to enable remote monitoring and scenario reproduction. In addition, they need to possess cross-departmental digital collaboration capabilities and strong remote communication skills, so as to efficiently resolve on-site issues and drive production optimization. In intelligent professional settings, such engineers should be proficient in intelligent control systems and capable of accurately tuning robot parameters. They should be adept at applying deep learning technologies to enhance robots' autonomous decision-making capabilities, and be familiar with smart sensor networks to strengthen robots' adaptability to complex environments.

3 Construction of the curriculum system

To align with national policy directives and meet the defined connotation of industrial robot on-site engineers, the crux lies in developing a tailored curriculum system for talent cultivation in this field. This system must be compatible with the Chinese-characteristic apprenticeship model. Furthermore, it should be designed to foster the five core competencies—being proficient in operation, knowledgeable in technology, capable of management, good at collaboration, and innovative—thereby equipping graduates to thrive in digital and intelligent vocational scenarios.

3.1 Philosophy for curriculum system construction

3.1.1 Integrating work and study, blending theory with practice

The Chinese-characteristic apprenticeship system emphasizes school-enterprise dual-subject education. Under this model, the curriculum system should deeply integrate theoretical learning with hands-on practice. Higher vocational institutions provide apprentices with systematic theoretical instruction—covering topics such as robotic mechanical principles and fundamentals of electrical control—to help them establish a solid knowledge framework. Enterprises serve as the primary base for practical training, where apprentices engage in real-world projects under the guidance of master trainers. These projects include installing robot bodies, commissioning production lines, and optimizing processes. By immediately applying theoretical knowledge in authentic work scenarios, apprentices achieve a dynamic mutual transformation of knowledge and skills, thereby substantially enhancing their practical capabilities. For instance, in a robotics programming course, apprentices first master programming syntax and logic at college before entering the enterprise to undertake actual product programming tasks. They then refine their code based on real-time operational feedback, truly achieving the unity of knowledge and action.

3.1.2 Focusing on competencies, tailoring talent cultivation

The curriculum architecture centers on the core competencies of industrial robot on-site engineers—namely being proficient in operation, knowledgeable in technology, capable of management, good at collaboration, and innovative. Every course and instructional segment is tightly aligned with the development of these critical capabilities, while redundant content disconnected from actual job demands is systematically eliminated. Taking "proficient in operation" as an illustrative example, the curriculum encompasses precision control in robotic mechanical assembly, standardized practices in electrical wiring, and accuracy and efficiency in programming and debugging. This holistic approach is designed to fully develop apprentices' hands-on skills, ensuring that graduates precisely meet enterprise requirements for on-site engineers at the operational level and achieving targeted positioning in talent cultivation.

3.1.3 Pioneering digitalization and intelligence, facing the future

To keep pace with the rapid advancement of the manufacturing sector toward digitalization and intelligence, the curriculum must proactively integrate relevant frontier technologies. Beginning with foundational courses on data acquisition and analysis, apprentices learn to leverage data for optimizing robot performance and implementing predictive maintenance. The curriculum incorporates digital twin technology to construct virtual robot models, enabling interactive mapping between virtual control and real-world operations, thereby revolutionizing maintenance methodologies. Furthermore, it delves into the development of intelligent control systems and the application of deep learning algorithms, equipping apprentices with the capabilities required to address the complex demands of future smart factories. This approach solidifies the foundation for their long-term career development, ensuring they maintain a competitive edge amid the continuous wave of technological iteration.

3.2 Framework for curriculum system construction

3.2.1 School-enterprise collaboration, precision targeting

A high-caliber curriculum development team will be established, integrating seasoned enterprise engineers, technical experts, and leading faculty members from the college. The team will immerse itself in frontline production settings to comprehensively map out the daily responsibilities, technical challenges, and future trends facing industrial robot on-site engineers. This will be achieved through on-site observations, in-depth discussions with frontline engineers, and analyses of industry dynamics. Based on robust research findings, both parties will collaboratively deconstruct the core competencies required for the position. They will then precisely anchor the key knowledge points, skill sets, and the focal areas and difficulties of instruction. This ensures the curriculum remains tightly aligned with authentic production scenarios, achieving a seamless alignment between talent cultivation and industry demands.

3.2.2 Hierarchical progression, systematic growth

Aligned with apprentices' cognitive development patterns and professional growth trajectories, a layered, progressive curriculum structure is designed. In the introductory stage, foundational skills courses are offered, such as Industrial Robot Mechanical Structure Recognition, Fundamentals of Electrical Control Systems, and Basic Programming Syntax, to help apprentices gain preliminary exposure to robotic technology and master essential operational techniques. Progressing to the intermediate stage, integrated application courses are introduced. These courses blend technology knowledge, management concepts, and collaboration skills—exemplified by Robot Process Parameter Optimization, Production Line Resource Coordination, and Cross-disciplinary Project Collaboration—to comprehensively enhance apprentices' professional competence and prepare them to handle complex production tasks. Advancing to the advanced stage, the focus shifts to pioneering exploration of cutting-edge technologies and innovative application development. Courses such as R&D of Intelligent Robot Control Systems and Innovative Integration of Emerging Processes with Robotics are offered to stimulate apprentices' innovative potential.

3.2.3 Modular design, flexible combination

The curriculum system is deconstructed into relatively independent yet interconnected modules based on competency dimensions, such as the proficiency in operation module and the technology knowledge module. The course content within each module is self-contained, facilitating flexible customization and tailored training aligned with specific enterprise demands or apprentices' individual interests and strengths. For instance, apprentices specializing in robot programming and debugging may focus on strengthening the proficiency in operation module alongside programming-related courses within the digital-intelligent technology module. Those aspiring to excel in technology optimization would prioritize coursework combining the technology knowledge module with the innovation module. This not only accommodates diverse developmental needs among apprentices but also enables curriculum updates, ensuring a rapid response to the reform of industrial technologies.

3.2.4 Digital-intelligent integration, end-to-end infusion

A cluster of digital-intelligent signature courses is meticulously developed, with related technologies organically infused into traditional curricula. In operational courses, digital twin technology is deployed, enabling apprentices to simulate procedures and refine solutions within virtual environments prior to conducting physical validation on actual machinery, thereby significantly enhancing operational precision and efficiency. In process-oriented courses, big data analytics are utilized to optimize process parameters; robotic operational settings are adjusted in real time based on production data feedback to ensure the precise implementation of process specifications. Meanwhile, management courses incorporate digital management tools to improve the scientific rigor of resource allocation and decision-making. This comprehensive strategy facilitates a holistic transition of traditional pedagogical models toward full-scale digitalization and intelligence.

3.3 Content of curriculum system

Guided by the established philosophies and frameworks for curriculum development, and adopting modular design as the delivery vehicle, the competency requirements—namely being proficient in operation, knowledgeable in technology, capable of management, good at collaboration, and innovative—are translated into concrete curriculum modules. While each module independently targets the cultivation of specific competencies, they converge into an organic whole through the integration of digital and intelligent technologies. This structure facilitates a scaffolded progression of capabilities ranging from foundational skills to innovative applications, thereby providing systematic curricular support for the cultivation of on-site engineers.

3.3.1 Operational skills module

Industrial Robot Mechanical Systems: This course follows the school-enterprise collaborative delivery model under the Chinese-characteristic apprenticeship system. College faculty first provide systematic instruction on the principles of robotic mechanical architecture and key points of precision mating for core components. Master trainers from enterprises then conduct on-site demonstrations of assembly procedures for robot bodies and supporting jigs and fixtures in the assembly workshop. Apprentices subsequently engage in hands-on practice to master precision control and debugging methods for mechanical installation, cultivating rigorous, standardized competencies in mechanical assembly.

Industrial Robot Electrical Control Systems: After classroom-based study of electrical schematics and control cabinet wiring standards, apprentices transition to enterprise sites to participate in hands-on electrical wiring and debugging under the supervision of master trainers. The curriculum covers knowledge domains including motor drive and sensor signal processing. Apprentices can acquire practical skills in electrical fault diagnosis and remediation, significantly enhancing their command of electrical control systems.

Industrial Robot Programming Techniques and Applications: Apprentices commence with mastering the syntax of foundational programming languages and progress to drafting programs aligned with simplified enterprise production tasks. The curriculum advances to sophisticated motion control and offline programming applications. Integrated with real-machine debugging on the shop floor, this approach ensures apprentices attain proficiency in operating robotic programming systems.

Industrial Robot System Maintenance: The course employs a dual-track approach: on campus, simulated fault scenarios are utilized to deliver theoretical knowledge regarding maintenance and servicing. During job rotation internships in enterprise workshops, apprentices assume responsibility for routine inspections and scheduled maintenance of robotic equipment. This integration of simulated learning and field experience enables apprentices to accumulate practical operational expertise while developing a full lifecycle awareness of equipment stewardship.

3.3.2 Technology knowledge module

Fundamentals of Industrial Product Manufacturing Processes: College instructors invite cross-industry process experts to campus to deconstruct the process flows of classic products in sectors such as automotive, electronics, and pharmaceuticals, thereby helping apprentices establish a structured framework of technology knowledge. Concurrently, enterprise mentors share cutting-edge cases of process innovation involving current market-leading products. This dual input ensures apprentices develop a comprehensive understanding of the entire product process landscape, from fundamental principles to the latest industrial applications.

Parameter Setting and Optimization for Industrial Robot Systems: Drawing on enterprise production big data, this course analyzes the correlation between process parameters (e.g., pressure, speed) and robot performance. It explains how to utilize data analytics tools to precisely calibrate robotic parameters for critical operations such as motion control, grasping, and polishing. The curriculum ensures the precise implementation of process specifications, directly linking parameter optimization to measurable improvements in production quality.

3.3.3 Management competence module

Systems Engineering and Lean Production: This course incorporates successful lean production case studies from renowned enterprises to illustrate the application of systems engineering methodologies in production line planning and equipment selection. Apprentices are instructed in essential lean tools, including 5S methodology and Kanban systems. The curriculum is designed to cultivate a scientific management mindset, enabling apprentices to identify and eliminate waste, optimize workflows, and enhance overall operational efficiency.

Production Line Resource Orchestration and Scheduling: On campus, apprentices simulate production line operations and utilize information management software to formulate resource allocation plans. During job rotation internships in enterprises, they actively participate in real-time scheduling decisions concerning manpower, materials, and equipment. This immersive experience enables apprentices to effectively monitor the pulse of production, accumulating substantive managerial expertise to ensure the efficient flow of manufacturing operations.

3.3.4 Collaboration competence module

Interdisciplinary Communication and Team Collaboration Techniques: This course utilizes experiential learning formats, including scenario simulations, group debates, role-playing, and case studies, to hone apprentices' communication protocols when interacting with departments such as R&D, sales, and logistics. It imparts strategies for conflict resolution and cultivates a high level of emotional intelligence (EQ) essential for effective collaboration. The curriculum aims to foster seamless synergy among professionals from diverse academic backgrounds, ensuring smooth communication and cohesive teamwork.

Project Synergy in Practice: This course organizes immersive project-based learning experiences where apprentices collaborate with enterprise technicians and academic faculty on large-scale initiatives, such as production line upgrades. Participants navigate the complete project lifecycle—from needs assessment and solution design to implementation and final acceptance. This hands-on engagement is designed to forge strong team cohesion and a robust spirit of collaboration, preparing apprentices for the complexities of cross-functional project execution.

3.3.5 Innovation competence module

Frontier Technologies in Industrial Robots: This course features regular lectures delivered by distinguished experts from research institutions and pioneering figures in the robotics industry. Topics cover emerging trends in the application of Artificial Intelligence (AI), the Internet of Things (IoT), and advanced materials within the robotics domain. By exposing apprentices to these cutting-edge developments, the course aims to broaden their innovative horizons and inspire forward-thinking approaches to technological challenges.

Innovative Applications of Robotics: Adopting a joint school-enterprise topic sponsorship model, apprentices form teams to undertake process enhancement projects. The curriculum encourages exploration into the application of robots within novel technology development, such as the integration of 3D printing and robotics, and innovations in processing technologies for special materials. This challenge-driven approach is designed to ignite apprentices' creative potential and propel the practical implementation of process innovation on the factory floor.

3.3.6 Digital-intelligent application signature module

Data Acquisition and Intelligent Operation and Maintenance: This course covers sensor selection and data acquisition protocols, instructing apprentices in the use of big data analytics software to interpret robotic operational datasets. Emphasis is placed on formulating data-driven intelligent maintenance strategies designed to extend equipment service life and enhance the intelligence quotient (IQ) of operation and maintenance.

Applications of Digital Twin Technology: This course delves into the principles of digital twin modeling, guiding apprentices to construct high-fidelity virtual models of robotic systems and their operational environments. It emphasizes simulating operational scenarios and optimizing control strategies within the virtual space. By leveraging virtual-physical mapping, apprentices achieve remote monitoring and scenario reproduction, significantly boosting operation and maintenance efficiency and enabling predictive maintenance capabilities.

Foundations of Intelligent Robot Control System Development: This course explores the application of machine learning and deep learning algorithms within robotic control architectures. Aligned with real-world industry demands, apprentices engage in developing intelligent control systems capable of autonomous perception, decision-making, and obstacle avoidance. This curriculum bridges advanced computational theories with practical engineering, significantly elevating the intelligence quotient (IQ) of robotic systems deployed in complex industrial environments.

4 Conclusion

Through the development of this curriculum system—closely aligned with both the developmental needs of the industrial robot industry and the post requirements for on-site engineers—we lay a solid foundation for talent cultivation by leveraging scientifically grounded development philosophies, well-structured design frameworks, and comprehensive modular courses. Moving forward, it is imperative to continuously monitor industry dynamics, deepen school-enterprise collaboration, and flexibly refine the curriculum in response to evolving demands. This ensures that graduates are precisely matched to the shifting technological and market landscapes of the industrial robot sector, effectively driving the intelligent transformation of the manufacturing industry. Such efforts underscore the pivotal supporting role of vocational education in industrial upgrading, ultimately realizing the synergistic, sustainable co-development of the education and industrial sectors.

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