

Construction of School-Enterprise Training Standards for Intelligent Equipment Field Engineers from the Perspective of New Quality Productive Forces

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Abstract: With the in-depth advancement of school-enterprise integration of industry and education, multiple practical bottlenecks exist in the cultivation of field engineers in the intelligent equipment industry. Significant cognitive differences between schools and enterprises in defining the core competencies of field engineers, including proficient technology, skilled craftsmanship, on-site management, collaborative capability, and innovative awareness, lead to the absence of industry-adapted systematic training standards, thereby resulting in ambiguous training objectives, rigid evaluation systems, and insufficient supply of high-quality technical talents. Based on national strategies for the special training program of field engineers in vocational education, this study constructs a school-enterprise collaborative “three-dimensionality and four-stratification” training standard model targeting the intelligent equipment manufacturing industry. The research finds that the training standards for field engineers are not merely a simple combination of existing school and enterprise norms, but rather a dynamic, iterative competency system closely aligned with on-site industrial production demands.

Keywords: Intelligent Equipment Manufacturing; Field Engineers; School-Enterprise Collaboration; Training Standards

1. Introduction

The rapid development of the digital economy and its continued penetration across the entire manufacturing value chain are driving profound changes in on-site production management models: traditional, single-skilled operational roles are gradually being replaced by multi-skilled technical positions, whilst the boundaries between product research and design and actual manufacturing are steadily blurring.

The industry is facing a shortage of multi-skilled technical professionals who possess a comprehensive set of competencies spanning research and design, hands-on production, process control, and on-site management; field engineers are precisely the strategically scarce talent required to support industrial transformation and upgrading [1]. Shen et al. [2], grounded in the requirements of new-quality productive forces and the transition to smart manufacturing, addressed the issues of inadequate training mechanisms and incomplete standards for on-site engineers by establishing a collaborative training platform involving both universities and enterprises. Through this innovation in training mechanisms, they have provided a model for the standardised cultivation of industry talent. Zhou et al. [3], Addressing the issues of ambiguous training standards and insufficient collaboration in the training of on-site engineers under the framework of new-quality productive forces, have developed training models and standards based on institutional practice, which can serve as a reference for similar institutions in their educational development.

In 2022, the Ministry of Education and four other central administrative departments launched a special initiative. It clearly advocates adopting modern apprenticeship mechanisms to formulate standardized training criteria for field engineers for scarce posts in the intelligent manufacturing industry, with a target of cultivating no fewer than 200,000 professional field engineers nationwide by 2025. This initiative incorporates field engineer talent training into the national strategic layout, rendering the implementation of systematic standardized training frameworks an urgent industry and social requirement.

Against the backdrop of divergent concepts and resource allocation issues existing in current school-enterprise collaborative education, extensive relevant research has been conducted

in academic circles. Zhang et al. [4] addressed the mismatch between the training of intelligent equipment talents and industrial demands under the framework of new productive forces. Combining industry-education integration with digital education technologies, they established a standardized training system to boost the supply of talents for regional industries. Focusing on the imperfect training criteria for field engineers engaged in intelligent equipment under new productive forces, Chen et al. [5] built an education system based on the collaborative model of government, vocational institutions, industry associations, and enterprises. This model facilitates resource sharing and complementary advantages, offering references for standardized talent training in technical colleges. Aiming at the shortages of intelligent manufacturing talents, inadequate training quality, and outdated training standards under new productive forces, Yin et al. [6] constructed a competency-oriented school-enterprise collaborative education system, improved the standardized training pathways for field engineers, and supported the cultivation of interdisciplinary talents. To resolve the deficiencies in the order-based training mode for field engineers of intelligent equipment under new productive forces, Sha [7] developed a full-cycle education model integrating post, curriculum, competition, and vocational certificate with ideological guidance. The research optimizes training standards and improves the quality of talent training as well as the employment matching degree of vocational college graduates.

Xiang et al. [8] perfected the education system by building industrial colleges, implementing modern apprenticeships, and constructing diversified education platforms, providing a feasible paradigm for standardized field engineer training. Xue et al. [9] optimized talent cultivation quality and improved field engineer training standards by adjusting specialty settings, reforming curriculum systems, and strengthening faculty and training base construction to solve the shortage of high-end technical talents and inadequate school-enterprise connection. Tao et al. [10] improved the education mechanism and consolidated the effectiveness of standardized talent cultivation relying on industrial colleges and modern apprenticeships.

Judging from the implementation effects of

China's first batch of special pilot programs for field engineer training, profound structural contradictions still exist in talent cultivation. Schools and enterprises hold disjointed understandings of the core competencies of field engineers, namely proficient technology, standardized craftsmanship, on-site management, collaborative literacy and innovative capability. This hinders the establishment of scientific and systematic training standards, further leading to practical problems such as ambiguous training orientation, one-sided evaluation dimensions and insufficient supply of compound technical talents. Prevailing assessment mechanisms overly emphasize summative evaluation while neglecting whole-process learning tracking, making it difficult to quantitatively evaluate students' on-site operational proficiency, engineering problem-solving capacity and technical transformation performance. Fundamentally, the absence of standardized training criteria restricts in-depth school-enterprise collaboration, confining current cooperation to superficial resource exchange of venues and equipment and hindering the effective implementation of integrated talent cultivation schemes.

Such training dilemmas are particularly prominent in the intelligent equipment industry. With the accelerated technological iteration of the industry, traditional single-skill posts have been gradually transformed into comprehensive compound positions. Meanwhile, the industry has continuously raised access thresholds for product quality and safety production management, placing higher requirements on practitioners' comprehensive literacy including on-site operation, emergency fault disposal and cross-department collaboration. The lack of unified and clear training standards tends to result in two extreme problems in school-enterprise education. School-oriented training overemphasizes theoretical teaching, leading to graduates' inadequate practical ability and poor industry adaptability. By contrast, enterprise-based post training focuses merely on operational skills, resulting in insufficient theoretical foundation and limited long-term development potential of trainees. Against the background of new quality productive forces, constructing a standardized training system that conforms to vocational education laws and adapts to the transformation and upgrading of the intelligent equipment industry serves as the

core approach to break through the bottlenecks of field engineer cultivation.

2. Connotation Analysis and Construction Logic of Field Engineer Training Standards

2.1 Concept Definition and Core Competency Dimensions

The core focus of a field engineer lies in the production site, which serves not only as the vehicle for the practical application of technology but also as the primary setting for the creation of product value. Compared to ordinary frontline technical operators, field engineers are cross-disciplinary, multi-skilled professionals. Drawing upon a comprehensive set of competencies—including practical experience, technical expertise, on-site management, team collaboration, and technological innovation—they bridge the two key stages of product R&D and design and mass production, thereby breaking down the barriers between R&D implementation and industrial production. Based on the requirements of the role, the core competencies of a field engineer are categorised into three key attributes: Firstly, technical operational skills: the ability to proficiently install, commission, and maintain intelligent equipment; a thorough understanding of product process specifications and industry technical standards; and the capacity to swiftly resolve routine technical faults on production lines. Secondly, on-site management skills: the responsibility for coordinating and managing production line operations; the ability to organise production schedules based on lean manufacturing principles; and the capacity to coordinate the seamless integration between work teams and production processes through efficient collaboration. Thirdly, technical innovation: identifying process pain points and practical industrial needs at the production frontline, keeping pace with industry trends, and implementing practical improvements and technological innovations focused on process optimisation, quality enhancement, cost reduction, and increased production efficiency.

2.2 Dual Attributes of Training Standards: Integrated Unification of Educational and Occupational Specifications

As the top-level design for talent cultivation, training standards define talent specifications and implementation routes of education. Owing

to the interdisciplinary post characteristics of field engineers, their training standards possess both educational and occupational attributes. For one thing, they comply with the inherent laws and normative teaching requirements of vocational education in China; for another, they keep in line with long-term industrial development and conform to industrial codes, corporate post management systems, and employment criteria.

Such dual attributes preclude one-sided formulation of standards solely by colleges or enterprises. College-dominated training tends to prioritize theoretical teaching apart from actual production and results in insufficient practical capacity of students; standards formulated merely based on corporate production rules only satisfy short-term employment demands while ignoring trainees' long-term career development. Accordingly, educational and industrial standards shall be integrated around vocational comprehensive competencies to formulate unified compound training specifications, which distinguish specialized field engineer training from conventional school-enterprise order-based classes.

2.3 Expanded and Incremental Requirements for Training Standards Empowered by the Digital Economy

The digital economy has profoundly reshaped the industrial forms and competency boundaries of the intelligent equipment industry. On the basis of traditional competency requirements, it puts forward incremental training demands for the digital literacy of field engineers, which are embodied in three core capabilities. First, data-driven decision-making capability. Multi-source data, including equipment operating conditions, process parameters, and production losses, can be collected in real time throughout the intelligent manufacturing process. Field engineers are required to explore the intrinsic value of data, optimize production schemes, handle on-site abnormalities, and support production decision-making based on data analysis results. Second, human-machine collaborative operation capability. The large-scale application of industrial robots has transformed the production mode from manual equipment operation to human-machine collaboration. Engineers are expected to be familiar with the operating principles of intelligent equipment, master basic equipment

programming and parameter debugging skills, and adapt to the new intelligent manufacturing production mode. Third, the practical application capability of digital twin technology. Digital twin realizes the virtual-real mapping between physical production lines and digital models. Instead of mastering underlying algorithm development, engineers need to proficiently utilize digital twin platforms to conduct process simulation, fault prediction, and optimal scheme simulation, so as to empower production quality improvement with digital tools.

3. Construction of the “Three-Dimensional and Four-Hierarchy” Training Standard Model for Field Engineers from the Perspective of School-Enterprise Collaboration

Based on the previous connotation sorting and practical dilemma analysis, this study constructs a systematic “three-dimensional and four-hierarchical” model for field engineer training standards centered on school-enterprise collaboration, in line with the employment demands of the intelligent equipment industry and the educational laws of vocational education.

3.1 Overall Model Framework: One Core, Three Dimensions, Four Progressive Levels, and Four Collaborative Mechanisms

The model forms an integrated framework featuring one core leadership, three-dimensional supports, four progressive levels, and four institutional guarantees.

The one core takes on-the-job competency of enterprises as the central anchor, with all training standards formulated centering on actual industrial employment demands. The three dimensions consist of competency, teaching content, and assessment and evaluation. The competency dimension defines the scope of professional knowledge, technical skills, and comprehensive professional literacy required for field engineers. The content dimension matches competency objectives by setting targeted curriculum systems, training projects, and practical tasks. The evaluation dimension defines the qualification thresholds of various competencies and establishes standardized assessment criteria.

The four progressive levels follow the law of talent growth and divide competency cultivation into four staged and progressive stages: basic

operation, professional skill, comprehensive application, and innovative practice. The four collaborative mechanisms serve as implementation guarantees, covering four school-enterprise collaborative operation mechanisms including joint standard development, co-construction of curriculum systems, shared resource investment, and mutual recognized evaluation systems.

3.2 Vertical Stratification: Four-Level Ladder Progressive Competency Training Path

The competency development of field engineers follows a gradual growth principle. Vertically, the model divides the training system into four progressive levels with clarified training contents, implementation carriers and learning cycles at each stage.

The first level is basic operational competency. As the entry-level benchmark of talent cultivation, it requires trainees to be familiar with the operating specifications of the intelligent manufacturing industry, complete standardized basic production operations according to process drawings, and establish fundamental quality control awareness. This level is implemented through on-campus basic training and enterprise cognitive internship in the first training cycle.

The second level is professional technical competency. On the basis of basic operational proficiency, trainees are capable of independently completing core job tasks, conducting routine production line fault diagnosis, making simple production decisions, and developing preliminary process optimization thinking. Adopting the combined mode of on-campus specialized training and enterprise follow-up internship, this level corresponds to the second and third training cycles.

The third level is comprehensive application competency. At this stage, trainees transform from single-equipment operators into interdisciplinary talents proficient in process technology and on-site management. They are able to address complex on-site production problems with multidisciplinary knowledge, coordinate procedural connection, and participate in the daily operation and optimization of production lines. Dominated by enterprise on-the-job internship and comprehensive engineering project training, this level covers the fourth and fifth training cycles.

The fourth level is innovative practical

competency. As the highest-level training criterion, it requires trainees to deeply engage in production practice, propose practical schemes for process improvement, cost reduction and efficiency enhancement based on on-site operational pain points, and possess dual capabilities of technological innovation and team overall management. Implemented through full-cycle enterprise post internship, this level is arranged in the sixth training cycle.

3.3 Horizontal Integration: Four-Dimensional Competency Specifications of Technology, Management, Digital Literacy, and Professional Character

Within the four-tier vertical framework, the training standards for each level are designed in an integrated manner across four horizontal dimensions—technical competence, management competence, digital literacy, and professional ethics—to achieve a multidimensional structure of competency standards. Technical competence: includes engineering drawing and drafting, with the ability to interpret mechanical, electrical and process drawings; practical programming of intelligent equipment, with proficiency in operating CNC machine tools, industrial robots and automated production lines; process implementation, completing component machining and assembly in accordance with procedures; equipment fault diagnosis and repair, using diagnostic tools to identify and resolve on-site faults; and production data collection and basic data analysis, utilising information gathered from production lines to support manufacturing. Management Competence: Focuses on on-site production coordination, rationally allocating processes and production resources; end-to-end quality control, proficiently applying quality management tools to implement quality control standards; On-site safety management: identifying and mitigating workplace safety risks; Lean cost management: understanding the composition of production costs and implementing cost-saving measures throughout the production process. Digital literacy: Aligning with the digital transformation requirements of smart manufacturing, proficient in using industrial software such as CAD/CAM and MES; thorough understanding of smart factory system architecture and operational logic; ability to conduct process simulation and fault prediction using digital twin platforms; capable

of organising, scheduling, and maintaining human-machine collaboration units. Professional Ethos: Cultivating a spirit of craftsmanship that strives for perfection; possessing strong cross-departmental communication and teamwork skills; upholding responsibilities for workplace safety and product quality; developing a habit of self-directed, iterative learning to adapt to continuous technological advancements in the industry.

These four dimensions are mutually supportive and indispensable, forming a comprehensive, integrated competency framework for on-site engineers.

4. Implementation Path and Guarantee Mechanism of the “Three-Dimension and Four-Hierarchy” Training Model

To address the fragmentation of training standards, superficial school-enterprise cooperation, and formalized evaluation in the current school-enterprise cultivation of intelligent equipment field engineers, and to ensure the effective implementation of the “three-dimension and four-hierarchy” training model in line with industrial talent demands under the context of new quality productive forces and digital economy, this chapter constructs a standardized and implementable model implementation system from three aspects: phased collaborative education, reconstruction of talent cultivation system, and long-term guarantee mechanism.

4.1 Phased Collaborative Implementation: Task Implementation of School-Enterprise Education with Divided Phased Rights and Responsibilities

Combined with the vocational college schooling system and the progressive growth law of skilled talents, this paper constructs a phased education model featuring school-led foundational cultivation, enterprise-led competency improvement, and whole-process collaboration, clarifying the phased educational rights and responsibilities of schools and enterprises to realize the gradual improvement of students’ comprehensive competencies. In the basic cognition stage, teaching and fundamental practical training are undertaken mainly by vocational colleges, while enterprises assist with industrial cognition lectures, enabling students to master basic intelligent manufacturing operations and safety specifications and

consolidate their foundational professional competencies. In the professional advancement stage, supported by the school-enterprise collaborative education mechanism, colleges deliver professional theoretical teaching and core practical training, and enterprise technical instructors provide on-campus guidance combined with short-term follow-up internships, cultivating students' core professional capabilities, including equipment programming, fault troubleshooting, and process optimization. In the comprehensive application stage, enterprise on-the-job internships and comprehensive project training serve as the core teaching carriers, promoting students' transformation from single operational skills to compound competencies covering process application and on-site management. Colleges conduct synchronous supervision and guidance to make up for students' theoretical deficiencies. In the innovation and quality improvement stage, based on enterprise full-time post internships, students are guided to carry out innovative practices such as process improvement, cost reduction, and efficiency enhancement, targeting practical production pain points, so as to cultivate their capabilities of technological innovation and team management, and realize the cultivation of high-level compound talents.

4.2 System Reconstruction: Optimization and Upgrading of Curriculum, Faculty, and Evaluation Adapted to the Training Model

To adapt to the educational logic of the proposed model and overcome the inherent shortcomings of traditional vocational education, this paper reconstructs the talent cultivation system from three dimensions of curriculum, faculty, and evaluation, providing core support for standardized talent training. In accordance with the four-level progressive competency requirements, a hierarchical and modular curriculum system is established, with digital courses including digital twin technology, human-machine collaboration, and production data application added to realize the precise docking of curriculum content with post requirements in the intelligent equipment industry. A two-way school-enterprise faculty cultivation mechanism is developed to encourage college teachers to participate in on-site enterprise practice, while recruiting enterprise technical backbones and senior field engineers as part-time instructors, forming a

dual-qualified teaching team tailored for compound talent cultivation. Abandoning the traditional evaluation mode that emphasizes results over processes, this study constructs a four-dimensional quantitative evaluation system covering process performance, final achievement, enterprise assessment, and innovative practice. The refined evaluation criteria at each stage enable the quantitative and traceable assessment of students' competency growth.

4.3 Long-Term Guarantee: Multi-Dimensional Safeguard Mechanism for School-Enterprise Collaborative Education

Centering on the core "four-mechanism collaboration" advantage of the proposed model, this study constructs a comprehensive and sustainable long-term educational guarantee system to solve the prominent problems of superficial cooperation and insufficient sustainable development capacity in school-enterprise collaborative talent cultivation. A joint expert team composed of professional teachers, enterprise technicians and industrial industry experts is established to dynamically update and revise training standards according to the iterative development demands of industrial digitalization. This mechanism unifies the educational cognition of all collaborative parties and ensures that the formulated training standards comply with both standardized vocational education norms and practical industrial development demands. Schools and enterprises jointly develop project-based teaching resources, and integrate enterprise process specifications, practical production cases and digital manufacturing standards into daily teaching, effectively bridging the disconnection between theoretical teaching and industrial production practice. Both parties integrate high-quality teaching resources, including professional teachers, intelligent manufacturing equipment, standardized training venues and enterprise post resources, to jointly build a digital teaching platform, which provides sufficient resource support for hierarchical progressive cultivation and innovative practical teaching. Furthermore, a tripartite mutual recognition evaluation system involving colleges, enterprises and industrial institutions is established to implement whole-process joint assessment and evaluation. This system eliminates the inherent drawbacks of

single-subject evaluation, and effectively improves the overall cultivation quality and industrial recognition of professional talents.

4.4 Expected Implementation Effects of the Model

The proposed “three-dimensional and four-hierarchy” school-enterprise collaborative training model effectively addresses the core problems existing in the cultivation of intelligent equipment field engineers, including the lack of systematic training standards, cognitive divergence between schools and enterprises, and low adaptability of cultivated talents to industrial posts. Integrating the inherent educational laws of vocational education with the practical industrial demands driven by new quality productive forces and digital economy development, this model comprehensively optimizes students’ technical operation capabilities, on-site management capabilities, digital literacy, and comprehensive professional literacy through hierarchical progressive training paths, multi-dimensional systematic competency standards, and sound collaborative guarantee mechanisms. This study provides a feasible and referential practical paradigm for the specialized cultivation of field engineers in the intelligent equipment industry, and supports higher vocational colleges in cultivating high-quality compound technical and skilled talents that meet the urgent demands of industrial transformation and upgrading.

Under the strategic background of new quality productive forces development and digital transformation of the manufacturing industry, this study targets the key bottlenecks in the school-enterprise collaborative cultivation of intelligent equipment field engineers, including inconsistent educational cognition between collaborative parties, imperfect systematic training standards, and disjointed training and practical application. A “three-dimensional and four-hierarchical” school-enterprise collaborative training standard model is constructed, forming a complete educational framework and scientific implementation path that adapts to industrial development demands and conforms to the essential laws of vocational education. The proposed model breaks the limitations of traditional shallow school-enterprise cooperation, which merely relies on resource complementarity. It promotes the in-depth integration and unified alignment of

training standards, educational objectives, and evaluation mechanisms between schools and enterprises, and effectively resolves the structural dilemmas in the cultivation of compound field engineering talents. The high-quality cultivation of field engineers serves as a core supporting factor for the sustainable and high-quality development of the intelligent manufacturing industry. Subsequent research and practical exploration will further rely on in-depth school-enterprise collaborative innovation, continuously optimize professional training standards and collaborative educational mechanisms, steadily improve the cultivation quality of compound technical and skilled talents, and facilitate the in-depth integration of industry and education, as well as the high-quality transformation and upgrading of the manufacturing industry.

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