Frontiers in Educational Research
ISSN 2522-6398 Vol. 9, Issue 6: 79-88, DOI: 10.25236/FER.2026.090611

Innovative Talent Cultivation in Intelligent Manufacturing: Integrating General-Vocational Coordination and High-End Digital Joint Laboratories

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Abstract: *The rapid evolution of intelligent manufacturing necessitates a paradigm shift in engineering education, demanding talents who possess both robust theoretical foundations and advanced practical skills. The traditional dichotomy between general and vocational education, however, frequently produces structural mismatches in talent supply. This paper explores an optimized training mode for intelligent manufacturing professionals under the coordination of general and vocational education, anchored by the construction of a high-end digital manufacturing school-enterprise joint laboratory. Drawing upon the empirical practices of Lingnan Normal University, particularly its Industrial Robot Science-Industry-Education Integration Practice Teaching Base and the digital empowerment of experimental teaching management, this study proposes a tripartite model encompassing curriculum integration, platform digitalization, and collaborative governance. By leveraging the Internet of Things, artificial intelligence, and Mixed Reality, the joint laboratory transcends conventional boundaries and enables the seamless integration of theoretical instruction, virtual simulation, and industrial application. The discussion elaborates on how this coordinated model enhances students' practical competencies, operationalizes the 1+X certificate system, and fosters a double-qualified teaching faculty. Empirical outcomes, including substantial gains in resource utilization, student innovation awards, and regional technology transfer, indicate that the synergy of general-vocational coordination and digital empowerment provides a scalable and replicable blueprint for modern engineering education reform.*

Keywords: *General-Vocational Coordination; Intelligent Manufacturing; Digital Empowerment; School-Enterprise Joint Laboratory; Talent Cultivation Mode*

1. Introduction

The strategic imperative of Made in China 2025 has positioned intelligent manufacturing as a core driver of industrial transformation, imposing unprecedented demands on the engineering workforce. The convergence of cyber-physical systems, industrial robotics, and data-driven production has fundamentally redefined the competency profile that employers expect from graduates [9]. Modern manufacturing enterprises no longer seek operatives with singular, narrowly defined skills; rather, they require compound talents equipped with systemic thinking, digital literacy, and the agility to navigate complex, interconnected production environments. The engineer of the intelligent manufacturing era must be able to interpret algorithms, configure networked equipment, diagnose faults across heterogeneous systems, and continuously adapt to technological change.

This transformation coincides with a broader movement toward an intelligent educational ecology, in which information technology is no longer an auxiliary tool but a constitutive element of the learning environment [1]. As universities embrace educational informatization, the locus of instruction shifts from the static transmission of knowledge toward the orchestration of data-rich, interactive learning experiences [9]. Engineering education, situated at the intersection of these technological and pedagogical currents, is therefore under particular pressure to reinvent both what it teaches and how it teaches.

Despite this clear industrial trajectory, higher education systems frequently grapple with a persistent structural flaw: the chasm between general education, which emphasizes theoretical breadth, and vocational education, which prioritizes procedural skills. This dichotomy results in graduates who either lack the practical acumen to operate advanced machinery or possess insufficient theoretical depth to innovate and optimize processes [2]. The consequence is a structural mismatch in which the volume of graduates does not translate into a corresponding supply of industry-ready talent, leaving enterprises to shoulder substantial retraining costs and slowing the diffusion of advanced manufacturing techniques.

The research and practice of optimizing the training mode of intelligent manufacturing professionals under the coordination of general and vocational education emerge as a direct response to this systemic bottleneck, advocating for a fluid, integrated educational continuum rather than two parallel and isolated tracks. Concurrently, the establishment of a high-end digital manufacturing talent training school-enterprise joint laboratory represents the physical and digital nexus where this coordination is actualized. By intertwining the resources of academic institutions with the technological frontier of industry leaders, and superimposing a layer of digital intelligence upon traditional laboratory management [6, 7], it becomes possible to construct an educational ecosystem that is simultaneously academically rigorous and industrially relevant.

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This integrated approach addresses the fundamental disconnect between academic theory and industrial practice that has long plagued engineering education. In traditional models, students often encounter advanced manufacturing technologies only after graduation, when they must learn on the job under pressure. The joint laboratory model creates a seamless transition by exposing students to real industrial scenarios, cutting-edge equipment, and authentic production challenges throughout their academic journey. This immersion not only accelerates skill acquisition but also cultivates the critical thinking and problem-solving abilities that are essential for innovation in intelligent manufacturing environments.

Furthermore, the digital intelligence layer applied to laboratory management transforms passive learning into active, data-driven engagement. Students can access real-time production data, simulate various manufacturing scenarios, and receive immediate feedback on their performance. This creates a learning environment that mirrors the complexity and dynamism of modern industrial settings, preparing graduates to hit the ground running in their professional careers. The laboratory becomes not merely a space for hands-on practice, but a living ecosystem where theoretical knowledge and practical application continuously inform and enhance each other.

The success of this model depends on the establishment of robust partnerships between educational institutions and industry partners, where both parties contribute resources, expertise, and real-world challenges. Such collaborations ensure that curricula remain current with technological advancements and that students develop the specific competencies that employers actually need. By bridging the gap between academia and industry, this approach creates a virtuous cycle where educational institutions produce more relevant graduates, and industries gain access to a pipeline of talent that can drive their digital transformation initiatives forward. This paper utilizes the empirical case of Lingnan Normal University to delineate the architectural framework, implementation pathways, and evaluative outcomes of this innovative talent cultivation paradigm. It argues that the synergy of general-vocational coordination and digital empowerment is indispensable for the future of manufacturing education. The remainder of the paper is organized as follows: Section 2 establishes the theoretical framework and diagnoses the structural challenges of conventional models; Section 3 constructs the optimized training model and details its digital infrastructure; Section 4 examines implementation through collaborative synergy; Section 5 reports outcomes, innovations, and regional impact; and Section 6 concludes with reflections and a future outlook.

2. Theoretical Framework and Structural Challenges

2.1 The Epistemology of General-Vocational Coordination

The concept of general-vocational coordination is not merely an administrative adjustment but an epistemological reconfiguration of engineering pedagogy. In the context of intelligent manufacturing, coordination implies the harmonization of scientific principles with technical praxis, ensuring that students are conversant in both the algorithmic foundations of robotics and the operational realities of assembly lines [2]. Knowledge and skill are treated not as separable commodities but as mutually constitutive dimensions of professional competence, each reinforcing and validating the other.

This reframing repositions the laboratory as the central site where abstract theory is rendered tangible and where tacit operational knowledge is articulated and elevated by scientific understanding. Under a coordinated model, a student who studies the mathematics of control theory is expected, within the same learning cycle, to tune a physical servo system and to interpret its empirical response [8]. The pedagogical objective is to dissolve the perceived hierarchy that subordinates practice to theory, replacing it with an iterative loop in which conceptual learning and applied experimentation continuously inform one another.

2.2 Structural Deficiencies in Traditional Laboratory Models

Traditional educational models are encumbered by rigid institutional boundaries. General undergraduate programs often relegate practical training to ancillary laboratory sessions where the equipment is outdated and the pedagogical approach is verification-based, leaving students unprepared for open-ended industrial challenges [4]. Conversely, vocational programs may over-index on equipment-specific operation at the expense of adaptive engineering design, rendering graduates vulnerable to technological obsolescence as production lines are upgraded.

Furthermore, the management of experimental resources in traditional settings is notoriously inefficient. Equipment is siloed within departmental domains, scheduling is rigid and bureaucratic, and safety oversight relies on human vigilance rather than intelligent monitoring [3]. The absence of a unified digital infrastructure means that invaluable data regarding student performance, equipment utilization, and pedagogical efficacy remain uncaptured and unanalyzed [5], depriving educators of the evidence needed to refine instruction.

These structural deficiencies underscore the necessity of a holistic intervention, one that the high-end digital manufacturing joint laboratory is uniquely positioned to provide. By serving as a shared, digitally augmented platform, the joint laboratory dissolves the artificial barriers between general and vocational tracks, fostering a continuum in which theoretical knowledge is immediately interrogated through practical application and vocational skills are continually elevated by scientific reasoning. Table 1 contrasts the salient characteristics of the traditional model with those of the coordinated, digitally-empowered model proposed in this study.

Table 1: Comparison between the traditional laboratory model and the coordinated, digitally-empowered model.

Dimension	**Traditional model**	**Coordinated, digitally-empowered model**
Education tracks	General and vocational tracks isolated	Integrated continuum across both tracks
Resource scheduling	Manual, days-long bureaucratic booking	Instantaneous intelligent scheduling
Equipment status	Siloed, periodically inspected by staff	IoT-monitored with predictive maintenance
Access control	Staffed, restricted operating hours	Unstaffed, face-recognition, extended hours
Learning data	Largely uncaptured and unanalyzed	Continuously captured and analytically modeled
Pedagogy	Uniform, verification-based exercises	Personalized, project- and inquiry-based

3. Constructing the Optimized Training Model

3.1 Curricular Integration and the Dual-Mandate Context

The optimized talent cultivation model is constructed upon three interdependent pillars: the integration of curricular pathways, the deep digitalization of the learning environment, and the substantive engagement of industry partners. At Lingnan Normal University, the Industrial Robot Science-Industry-Education Integration Practice Teaching Base, established in collaboration with Shenzhen Huazhong CNC and Hunan Keruite Technology, serves as the empirical manifestation of this model.

The institutional context is particularly apt, as the university hosts both general engineering majors, such as Robotics Engineering and Mechanical Design, Manufacturing and Automation, and vocational-education-oriented majors such as Mechatronics Technology Education [3]. This dual mandate necessitates a curricular architecture that is both flexible and coherent, allowing students to traverse a continuum from foundational theory to specialized, industry-aligned competencies. Rather than maintaining two disconnected curricula, the program defines shared milestones at which students from different tracks converge on common projects, each contributing complementary expertise.

The joint laboratory provides the substrate for this traversal. Instead of bifurcating resources, the laboratory functions as a centralized hub where general-education students engage in deep-practice projects and vocational-education students access advanced algorithmic and systemic design frameworks. This coordination is optimized through a project-based learning paradigm, in which theoretical concepts from control theory and artificial intelligence are applied to tangible industrial problems, such as the development of automated assembly lines or intelligent agricultural picking robots [2]. The result is a curriculum in which assessment is anchored not in isolated examinations but in the demonstrable performance of integrated engineering tasks.

3.2 Digital Empowerment of the Laboratory Ecosystem

The second pillar, and the most transformative, is the comprehensive digital empowerment of the laboratory ecosystem. The traditional model of laboratory management, characterized by manual booking, fragmented equipment oversight, and reactive maintenance, is fundamentally incompatible with the dynamic needs of intelligent manufacturing education [3]. To resolve this, the university has deployed an intelligent experimental teaching and management platform built upon Internet of Things and artificial intelligence technologies [6, 7].

This system is organized as a four-layer framework comprising a perception layer, a network layer, a platform layer, and an application layer, which collectively orchestrate the entire lifecycle of laboratory operations [7]. Each layer encapsulates a distinct technical responsibility, yet the layers are tightly coupled so that data sensed at the equipment level flows upward to inform analytics and, in turn, control decisions propagate downward to the physical environment. Table 2 summarizes the composition and function of each layer, and the overall architecture is depicted in Figure 1.

Table 2: The four-layer architecture of the smart experimental teaching and management platform.

Layer	**Core components**	**Primary function**
Perception	Industrial robots, CNC machines, 3D printers, smart sensors, RFID, cameras	Acquire real-time status, environmental and operational data
Network	Wi-Fi 6, 5G, industrial Ethernet, MQTT / OPC UA gateways	Transmit data securely between devices and the platform
Platform	Data lake, AI and big-data engine, identity and access management	Store, integrate and analyze structured and unstructured data
Application	Scheduling, VR/AR experiments, automated grading, safety monitoring, 1+X management	Deliver teaching, management and decision-support services

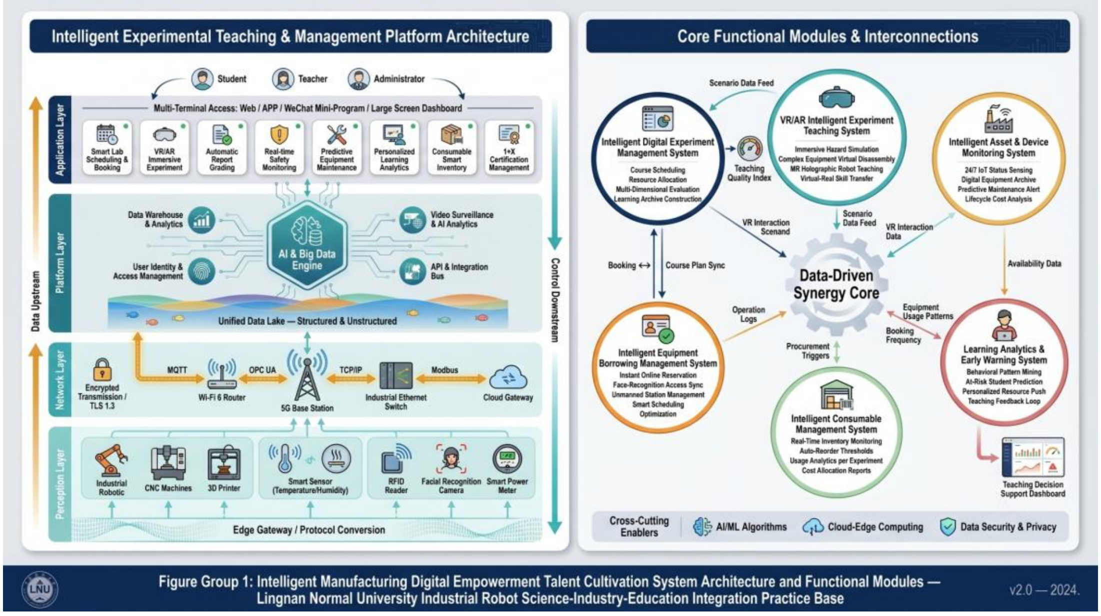

Figure 1. Architectural framework and functional modules of the smart experimental teaching and management platform.

Through this digital infrastructure, the laboratory is transformed from a static repository of machines into an intelligent, responsive environment [6]. Core teaching devices, including CNC machines, industrial robots, and 3D printers, are retrofitted with smart sensors and communication modules, enabling real-time telemetry and remote monitoring. This connectivity fundamentally alters resource allocation; the intelligent scheduling system synchronizes equipment availability with curricular demands and individual student requests, effectively transitioning the booking process from a days-long bureaucratic procedure into an instantaneous digital transaction [5].

The integration of facial recognition and IoT-enabled access control ensures secure, unstaffed laboratory operation, extending access hours and fostering a culture of autonomous exploration [6]. Students can reserve a workstation, gain authenticated entry, and complete a guided experiment outside conventional class hours, while the platform records every interaction for later review. This shift not only relieves the chronic bottleneck of equipment access but also signals a pedagogical trust in student initiative that is itself formative.

The digital empowerment extends beyond logistics into the very heart of pedagogy. The platform features a comprehensive digital resource library in which interactive experimental guides are accessible via QR codes, and standard operating procedures are preserved in high-definition video [9]. Most critically, the system autonomously captures granular data on student performance, tracking operational duration, procedural fidelity, and experimental outcomes. This data is subjected to analytical algorithms that not only automate the grading of experimental reports but also generate predictive insights, identifying students who require pedagogical intervention and enabling a shift from uniform instruction to personalized mentorship.

3.3 The Theory-Virtuality-Reality Learning Loop

A defining feature of the model is the coupling of virtual and augmented reality simulations with physical equipment. By allowing students to safely rehearse complex or hazardous operations in a virtual domain before executing them on physical machinery, the platform optimizes what may be termed the theory-virtuality-reality learning loop [4]. Learners first acquire conceptual understanding, then validate it in a risk-free simulated environment, and finally consolidate it through authentic operation of industrial hardware.

This loop yields several pedagogical benefits. It compresses the time required to reach operational competence, reduces the consumption of consumables and the risk of equipment damage during early learning, and provides a controlled setting in which failure becomes a constructive part of the learning process [4, 8]. Because each pass through the loop is instrumented and recorded, instructors gain a longitudinal view of skill acquisition that informs the timing and content of subsequent interventions.

4. Implementation and Collaborative Synergy

4.1 Deep Enterprise Integration and Collaborative Governance

The operationalization of this coordinated, digitally-empowered model is deeply reliant on the substantive integration of enterprise resources, moving beyond perfunctory internship placements toward a collaborative governance structure [10]. The partnership with Shenzhen Huazhong CNC and Hunan Keruite Technology exemplifies this deep integration, wherein the joint laboratory functions as a shared space for talent incubation, technological research and development, and pedagogical innovation. Governance responsibilities, including curriculum review, project selection, and assessment standards, are exercised jointly by academic and industrial stakeholders.

Enterprise involvement is systemic; industry experts serve as adjunct faculty, directly co-instructing experimental modules and ensuring that the curriculum remains synchronized with the latest technological paradigms [10]. This collaboration is particularly evident in the design of advanced project-based modules that mirror real industrial scenarios. For instance, the initiative to develop a deep-learning, vision-based mobile robot for dragon fruit harvesting represents a convergence of academic research and regional agricultural needs.

In this project, students from both general and vocational tracks collaborate, with general-education students focusing on algorithmic optimization and machine vision while vocational-education students concentrate on the electromechanical integration and operational deployment of the mobile platform. Such projects epitomize general-vocational coordination, demonstrating how diverse skill sets can be synergized within a digitally-managed collaborative framework to produce viable technological solutions [2]. The laboratory thereby becomes a setting in which authentic engineering uncertainty, rather than a predetermined answer, drives the learning experience.

4.2 The 1+X Certificate System

The joint laboratory also serves as critical infrastructure for the 1+X certificate system, a cornerstone of China’s vocational education reform that encourages students to acquire vocational skill certificates alongside their academic diplomas. By establishing the FANUC Robot Authorized Training Center and the Western Guangdong Industrial Robot Vocational Qualification Assessment Base, the laboratory seamlessly embeds industry-recognized credentialing into the academic pathway [2].

This facility annually trains and assesses dozens of students and members of the broader workforce, significantly enhancing their employability and ensuring that the competencies validated by the university are directly aligned with market demands. The digital management platform further facilitates the scheduling and administration of these certification processes, creating a streamlined pipeline from training to assessment in which examination records, equipment allocation, and candidate progress are managed within a single system [5].

4.3 Cultivating a Double-Qualified Faculty

The cultivation of a double-qualified teaching faculty, comprising educators who hold both academic qualifications and demonstrable industrial competence, is another critical outcome of this synergistic implementation [3]. The digital platform’s data analytics provide educators with precise feedback on pedagogical efficacy, while structured corporate secondments and joint research and development projects ensure that faculty maintain cutting-edge industrial competencies.

With more than ninety-five percent of the base’s teaching staff achieving double-qualified status, the institution has successfully bridged the academic-industrial divide at the instructional level. This ensures that the coordination of general and vocational education is modeled by the educators themselves, lending credibility to the integrated curriculum and providing students with mentors who can move fluently between conceptual explanation and hands-on demonstration.

5. Outcomes, Innovations, and Regional Impact

5.1 Pedagogical and Operational Outcomes

The empirical outcomes of implementing this optimized training model at Lingnan Normal University provide compelling evidence for its efficacy. The digital empowerment of laboratory management has yielded quantifiable improvements in resource utilization; the transition to intelligent scheduling and unstaffed operation has significantly alleviated the bottleneck of equipment access, allowing more time for deep, exploratory practice [6].

The predictive maintenance algorithms and IoT monitoring have reduced equipment downtime and safety incidents [3, 7], while the automated grading of experimental reports has liberated faculty to engage in higher-order mentoring rather than routine marking. Pedagogically, the integration of VR and AR simulations and the scan-to-learn digital resources have fostered greater student autonomy and procedural fluency [8], with students increasingly able to prepare for and self-direct their laboratory work.

Equally important is the quality of the data that the platform accumulates over successive cohorts. Because every booking, operation, and assessment is logged, the institution gradually constructs a longitudinal record of how competencies develop across the curriculum [5]. This record supports evidence-based revision of laboratory exercises, the early identification of high-potential and at-risk students, and a continuous feedback loop between teaching design and measured learning outcomes. Over time, the laboratory therefore behaves less like a fixed facility and more like an adaptive instrument that improves in step with the students it serves.

5.2 Student Achievement and Innovation

The coordination of general and vocational pathways, facilitated by the joint laboratory, has resulted in exceptional student achievements. Over the past three years, students have secured more than one hundred provincial and national awards in disciplines ranging from mechanical innovation to advanced mapping, and have obtained twenty-seven authorized invention and utility model patents.

The robust engagement in innovation and entrepreneurship projects, with nearly a thousand participants, underscores the model’s success in cultivating an applied, innovative mindset [2]. These achievements are not incidental; they are the natural product of a learning environment in which students routinely confront authentic problems, iterate on real prototypes, and present their results to audiences that include industry practitioners.

The breadth of these accomplishments, spanning disciplinary competitions, patented inventions, and entrepreneurial ventures, also reflects the complementary contributions of the two educational tracks. General-education students tend to lead the conceptual and algorithmic dimensions of a project, whereas vocational-education students excel in fabrication, integration, and field deployment; when these strengths are combined within a single team, the resulting work is both technically sophisticated and practically robust.

5.3 Regional Economic Contribution

Beyond the campus, the model has generated substantial regional impact, fulfilling the imperative that higher education institutions serve local economic development. The joint laboratory has emerged as a vital technical resource for Western Guangdong, providing targeted training for more than four hundred enterprise technicians and facilitating technology transfer through horizontal research projects exceeding one million yuan in funding [10].

The focus on regional industries, such as the smart agricultural equipment research center targeting local fruit cultivation and the smart home appliance assembly robot platform supporting the local manufacturing cluster, demonstrates a strategic alignment between educational output and industrial demand. The achievements in securing national and provincial research grants, alongside accolades such as the China Machinery Industry Science and Technology Award, validate the capacity of the coordinated, digitally-empowered model to generate high-quality scientific outputs that are directly applicable to industrial advancement.

This regional orientation also creates a virtuous circle between education and local development. Enterprises that benefit from the laboratory's training and technology transfer become more willing to contribute equipment, problems, and personnel to the joint platform, which in turn enriches the learning environment for students [10]. The university thereby positions itself not as a detached provider of credentials but as an embedded node in the regional innovation system, translating its teaching and research capacity into tangible economic and social value for Western Guangdong.

5.4 The Innovation of Systemic Integration

The innovation of this model lies in its systemic integration. It does not treat general-vocational coordination, digital transformation, or industry collaboration as isolated interventions, but as mutually reinforcing components of a singular educational ecosystem [1]. The digital platform makes coordination measurable and manageable; the coordinated curriculum gives the digital platform meaningful pedagogical content to orchestrate; and deep enterprise collaboration ensures that both remain anchored to real industrial requirements [10].

It is this mutual reinforcement, rather than the adoption of any single technology or policy, that distinguishes the approach and accounts for its replicability. An institution seeking to adapt the model need not possess identical equipment or partners, but it must preserve the structural relationship among the three pillars, allowing each to amplify the others.

6. Conclusion and Future Outlook

The optimization of intelligent manufacturing talent cultivation requires a fundamental departure from traditional, siloed educational architectures. This paper has demonstrated that the coordination of general and vocational education, when anchored by a high-end digital manufacturing school-enterprise joint laboratory, offers a potent solution to the persistent misalignment between academic training and industrial requirements [2]. The Lingnan Normal University case study illustrates that digital empowerment is the critical catalyst in this paradigm, transforming the laboratory from a passive, resource-constrained environment into an intelligent, data-driven ecosystem that facilitates seamless theory-practice integration, personalized learning, and rigorous safety and quality control [6, 7]. By embedding industry-recognized certifications, fostering deep enterprise collaboration in research and development, and cultivating a double-qualified faculty, the model ensures that graduates are not merely theoretically informed or procedurally trained, but are agile, innovative professionals equipped for the complexities of modern manufacturing [3].

As intelligent manufacturing continues to evolve, the continued refinement of this model, particularly through the integration of emerging technologies such as digital twins and the expansion of regional resource-sharing networks, will be essential [1, 9]. Future work should also seek to establish longitudinal metrics that track graduate performance in industry, thereby closing the evaluative loop between educational design and professional outcomes. The paradigm presented herein offers a robust, scalable framework for engineering education reform, advocating for a future in which the boundaries between general and vocational education are permeably mediated by digital intelligence and collaborative enterprise.

Looking ahead, the integration of digital twin technology stands to revolutionize the laboratory experience by enabling full-lifecycle simulation of complex manufacturing processes. For instance, students could design a production line in a virtual environment, test its operational efficiency under varying conditions, and then deploy the optimized configuration on physical equipment—all within a single, interconnected workflow. This capability not only deepens understanding of systemic interdependencies but also prepares learners to manage the digital-physical convergence that defines Industry 4.0. Moreover, the expansion of regional resource-sharing networks, facilitated by cloud-based platforms and standardized data protocols, will allow institutions to pool equipment, expertise, and industrial datasets, creating a distributed ecosystem where students access cutting-edge resources regardless of their physical location. Such networks would also enable cross-institutional collaborative projects, mirroring the distributed nature of modern supply chains and fostering a culture of open innovation.

The establishment of longitudinal evaluation metrics is equally critical. Beyond tracking immediate outcomes like student awards or equipment utilization, future research must focus on long-term indicators such as graduate employment rates in high-tech manufacturing, employer satisfaction with skill alignment, and the volume of technology transfer from academic projects to industrial adoption. These metrics would provide empirical evidence of the model's impact on workforce readiness and regional economic growth, while also generating feedback to refine curricula and laboratory modules. For example, if data shows that graduates struggle with specific aspects of predictive maintenance, the curriculum could be adjusted to include more hands-on training in IoT-enabled fault diagnosis, leveraging the laboratory's data analytics to target interventions precisely.

However, the path forward is not without challenges. The rapid pace of technological change in intelligent manufacturing necessitates a dynamic curriculum that can adapt to new tools, standards, and processes without disrupting the educational continuum. To address this, institutions must develop agile governance structures that involve industry partners in continuous curriculum review, ensuring that academic content remains synchronized with industrial evolution. Additionally, the proliferation of digital data raises concerns about privacy, security, and ethical use. Robust data governance frameworks, incorporating principles of transparency and consent, will be essential to maintain trust and comply with regulatory requirements while harnessing the power of learning analytics.

In conclusion, the coordinated, digitally-empowered model represents a paradigm shift in engineering education—one that transcends the artificial divide between theory and practice, general and vocational tracks. By leveraging digital intelligence to create an adaptive, industry-aligned ecosystem, this approach not only addresses current talent gaps but also builds the resilience needed to thrive in an era of constant technological disruption. As manufacturing continues to advance, the synergy of general-vocational coordination and digital empowerment will remain indispensable, offering a blueprint for educational institutions to cultivate the next generation of innovators who can bridge the gap between academic knowledge and industrial innovation.

Acknowledgement

1) Guangdong Provincial Undergraduate Higher Education Teaching Quality and Teaching Reform Engineering Construction Project (Grant No. [2024]-9-44).

2) Education and Teaching Reform Project of Lingnan Normal University (Grant No. [2024]-113-58). (Research and Practice on the Optimized Training Model for Specialized and Vocational Coordinated Development in Intelligent Manufacturing-related Professional Talents)

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