Analysis of the Multidimensional Characteristics and Innovative Training Paths of Highly Skilled Talents in the Context of New Quality Productivity

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Abstract: Against the backdrop of new quality productivity driving high-quality economic development, this paper examines how technological innovation, digital transformation, and green development reshape the competencies and training models of highly skilled talent. It analyzes multidimensional characteristics, including knowledge structure, innovation awareness, digital literacy, and cross-boundary collaboration, revealing a shift towards "innovative, composite, and intelligent" profiles. The study identifies misalignments in current vocational education, such as outdated curricula and insufficient industry-education integration. It proposes innovative training paths, including deep industry-education collaboration, digital-intelligent teaching, and lifelong learning ecosystems. Case studies validate the feasibility of aligning talent development with new quality productivity demands.

Keywords: New quality productivity; Highly skilled talent; Multidimensional characteristics; Industry-education integration; Digital teaching

1. Introduction

Amid accelerating technological and industrial transformation, artificial intelligence, big data, the Internet of Things, and cloud computing are fundamentally reconfiguring production modes and industrial structures, giving rise to a new quality productive force whose hallmarks are innovation-driven growth, intelligent leadership, and low-carbon development. This emerging form of productivity is both a key indicator of high-quality development and the principal engine for building a modern industrial system. Consequently, the knowledge structure and competence profile of high-skilled talent are undergoing a profound shift: from routine mechanical operations toward hybrid innovative capabilities that integrate creative thinking, digital literacy, and cross-disciplinary collaboration.

China's quest to evolve from a manufacturing giant into an intelligent-manufacturing power imposes more stringent requirements on human-capital quality. The deepening of industrial intelligence and the accelerated pace of knowledge renewal demand that workers move beyond single-skill mastery to sustained innovative capacity, while the rapid expansion of green, digital, and intelligent industries urgently calls for talents who possess comprehensive attributes, creative cognition, and technological adaptability. Although extant research has yielded valuable insights into vocational-education reform, industry-education integration, and innovative cultivation, most studies remain trapped in traditional analytical frameworks, lacking a systematic account of talent evolution under new quality productive forces and of its coupling mechanisms with technology-industry upgrading. Structural deficits in training models, evaluation systems, and learning ecosystems further constrain the construction of a multi-tier talent-supply system.

Adopting a combined theoretical and case-study approach, this paper systematically dissects the multidimensional characteristics of high-skilled talents—knowledge, skills, innovation, digitalization, and collaboration—diagnoses the core challenges confronting China's high-skilled talent training system, and proposes pathway innovations oriented to new quality productive forces. By deepening industry-education integration, building digital and intelligent teaching platforms, establishing a multidimensional, competence-based evaluation mechanism, and perfecting a lifelong learning ecosystem, the study aims to provide robust talent support for accelerating scientific and technological self-reliance and promoting high-quality economic development.

2. Theoretical foundations and contemporary features of new quality productivity

2.1. Connotation and constituent elements of new quality productivity

New quality productivity stands as a pivotal concept within the economic theory framework of the new era, serving as a core impetus for the transformation of social production modes and the advancement of high-quality economic development.

At its core, new quality productivity is characterized by technological innovation as the leading force, with digitalization, intelligence, and greening as its primary attributes. Highly qualified workers and highly skilled talent form the key support for its realization. In contrast to traditional productivity, which primarily depends on the inputs of capital, labor, and land, new quality productivity capitalizes on technological innovation and knowledge-intensive labor. Through technological progress, business model innovation, and organizational transformation, it achieves simultaneous enhancements in efficiency and innovative capacity. This shift represents a fundamental transition from "factor-driven" to "innovation-driven" growth, signifying humanity's entry into the era of the intelligent economy [1].

The concept of new quality productivity not only draws inspiration from but also advances the Marxist perspective that productivity emerges from the integration of science and labor. It is also in alignment with the contemporary demands of the digital economy, intelligent manufacturing, and green development. Traditional productivity is composed of three core elements: workers, means of labor, and objects of labor. In contrast, new quality productivity incorporates additional elements, namely technological innovation, human capital, and data resources. These additions render the productivity system more intelligent, networked, and collaborative [2].

Technological innovation serves as the primary driving force and fundamental engine behind the formation and escalation of new quality productivity. Breakthroughs in artificial intelligence (AI), 5G communications, quantum information, new energy, and biotechnology are continuously reshaping industrial structures and the division of labor.

The constituent elements of new quality productivity can be analyzed across four dimensions:

Technological innovation: As the core of new quality productivity, technological innovation encompasses not only technological breakthroughs but also institutional, managerial, and business model innovation. It drives the continuous evolution of production processes and enhances overall productivity.

Human capital: Highly skilled and knowledge-based workers are the main drivers of new quality productivity. Through creative labor, they convert knowledge into value and propel the ongoing evolution of the economy. Human capital, therefore, plays a crucial role in realizing the potential of new quality productivity [3].

Digital and information factors: Data has emerged as a new means of production. The widespread application of digital technologies tightly couples information, capital, and logistics, leading to a significant improvement in resource allocation efficiency. This integration of digital and information factors is essential for the realization of new quality productivity.

Green and sustainability factors: Under the "dual-carbon" goals, green technologies and clean energy are vital for achieving development that harmonizes humanity and nature while remaining innovation-driven. These factors ensure that new quality productivity is sustainable and environmentally friendly.

In summary, new quality productivity represents a comprehensive form of productivity centered on technological innovation, supported by human capital, and characterized by digitalization, intelligence, and greening. It functions not only as a new engine for economic growth but also as a force for optimizing production relations and restructuring the modern industrial system. As AI, big data, cloud computing, and blockchain increasingly converge, new quality productivity is poised to become a decisive force shaping the future. It offers a broad stage for the cultivation and value realization of highly skilled talent [4].

2.2. The reshaping of the economic structure by new quality productivity

Driven by new quality productivity—with innovation at its core and digitalization and greening as its key levers—the economic structure is undergoing a fundamental shift from a factor-driven model to an innovation-driven paradigm. Technological breakthroughs are permeating both industrial technology stacks and business models, steering industries away from mere "scale expansion" toward a coordinated optimization of efficiency, quality, and resilience. This transformation, in turn, triggers a systemic rebalancing of sectoral weights, value-chain specialization, and factor allocation.

Specifically, digitalization and intelligence are creating substantial value premiums in knowledge-intensive upstream sectors, such as core algorithms, advanced materials, and key components. In midstream manufacturing, the evolution is progressing from automation toward flexibility, platformization, and greening. Downstream, the economic role of services is shifting from a supportive function to being on par with physical products, driven by models like Product-as-a-Service and Data-as-a-Service. This trend is upgrading the internal structure of the tertiary sector and accelerating the expansion of producer services [5].

As data becomes a new critical factor of production, plummeting transaction costs and enhanced network externalities are catalyzing the formation of cross-industry and cross-regional collaborative ecosystems. This deepens specialization and rebuilds supply-chain resilience. Concurrently, under the dual pressures of green targets and constraints, improvements in energy efficiency and the growing penetration of clean energy are increasing output per unit of input, gradually decoupling economic growth from environmental pressure.

This series of transmission mechanisms and structural effects—illustrated in **Figure 1**—not only redefines the economic landscape but also provides clear direction for subsequent upgrades in talent structure and the reconstruction of training systems [6].
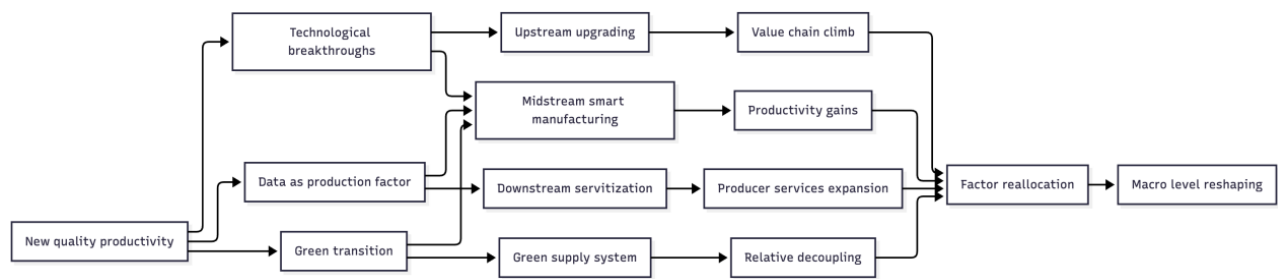
Figure 1. Transmission mechanism of new quality productivity reshaping the economic structure

As illustrated in **Figure 1**, new quality productivity operates through three core drivers—technological breakthroughs, data empowerment, and green constraints—which collectively reshape the economic structure along the industrial chain. In the upstream sector, it enhances bargaining power through core technologies and standards. In the midstream, it shifts the production function toward "stable quality, higher efficiency, and lower consumption" by means of industrial internet platforms and intelligent processes. Downstream, it drives business model innovation through servitization and datafication. Across the entire system, the green supply mechanism functions as a dual force, imposing constraints while creating incentives.

These drivers jointly generate four types of intermediary outcomes: value-chain upgrading, total factor productivity gains, high-end expansion of producer services, and relative decoupling of economic growth from environmental impacts. This leads to a reallocation of production factors across sectors, regions, and industrial forms, ultimately resulting in a macro-level restructuring characterized by higher-end industrial composition, networked regional division of labor, and collaborative industrial ecosystems [7].

For talent development and education systems, this structural transformation implies a fundamental shift in skill demand—from task-specific abilities toward integrated competencies that combine technological, digital, green, and service capabilities. Accordingly, training systems must be systematically re-engineered—encompassing curriculum design, practical learning scenarios, and evaluation mechanisms—to align with the transmission pathway depicted in **Figure 1**, thereby keeping pace with ongoing economic-structural upgrading [8].

3. Multidimensional characteristics of highly skilled talent under the lens of new quality productivity

Driven by the demands of new quality productivity, the competency structure of highly skilled talent is undergoing a fundamental transition—from a model of "specialized skill and procedural execution" to one of "composite knowledge, digital intelligence, and cross-boundary collaboration." To ground this analysis in an empirically traceable framework, the following examination adopts a structured methodological approach, illustrated here with a demonstrative sample (enterprises, $n = 120$; vocational colleges, $n = 18$; spanning manufacturing, energy, and digital services across eastern, central, and western regions). By integrating competency scales, job analysis data, and training records, we construct a multidimensional indicator matrix designed to ensure analytical transparency and methodological reproducibility. While the current data serve for demonstration, this specification provides a scalable framework for future rigorous statistical testing and robustness checks with comprehensive datasets [9].

3.1. Core competency dimensions and measurement

Within the four-dimensional task space defined by "technology, data, sustainability, and quality," the core competencies of highly skilled talent have evolved beyond procedural operation to encompass

system integration, parameter optimization, and continuous improvement. To quantitatively capture this multidimensional capability profile, a Composite Skills Index (CSI) is constructed by aggregating weighted sub-competency scores, with weights determined through expert evaluation. The resulting index is standardized to facilitate cross-sector comparison. As summarized in **Table 1**, the CSI reveals distinct competency patterns across industries, reflecting differentiated demands under the new quality productivity paradigm.

Table 1. Decomposition of the Composite Skills Index (CSI) and industry comparison (standardized 0–100)

Indicator	Weight	Intelligent mfg.	Green energy	Digital services	Overall mean
Engineering understanding & systems thinking	0.25	78.5	74.1	71.8	75.1
Process & equipment tuning	0.20	82.4	76.7	69.2	76.2
Quality & process improvement (QCC/Six Sigma)	0.15	75.3	72.5	68.6	72.1
Data analysis & visualization	0.20	70.8	69.4	81.3	74.3
Innovative design & experimentation (DoE)	0.10	73.1	70.2	66.8	70.2
Green & compliance awareness	0.10	69.8	82.6	65.2	72.5
Composite Skills Index (CSI)	-	76.5	75.7	72.3	74.8

As summarized in **Table 1**, intelligent manufacturing demonstrates a comparative strength in process tuning and engineering comprehension, whereas the green energy sector scores markedly higher in environmental and compliance awareness. Digital services, in turn, exhibit a structural advantage in data analysis capabilities. The overall CSI mean of 74.9 reflects that a composite skill profile has become the prevailing norm among highly skilled talent. To further examine the functional relevance of the CSI, job-level data were analyzed using Pearson correlation in an Overall Equipment Effectiveness (OEE)-oriented specification. The results show a significant positive association between the CSI and labor-hour output efficiency ($r = 0.62$, $P < 0.01$), indicating that composite skills are substantially linked to production performance [10].

3.2. Digital literacy and intelligent technology application

As a pivotal factor within the new quality productivity framework, data necessitates a set of transferable competencies spanning acquisition, feature processing, model interpretation, and human-machine collaboration. To operationalize this construct, a Digital Literacy Index (DLI) is formulated, encompassing five dimensions: data awareness, tool proficiency, automation scripting, model comprehension, and human-machine coordination. The distributions of DLI scores, categorized by region and firm size, are provided in **Table 2**.

Table 2. Digital Literacy Index (DLI) distribution (standardized 0–100)

Group	Data awareness	Tool proficiency	Automation scripting	Model understanding	H–M collaboration	DLI
East – Large firms	83.2	81.5	76.3	72.4	79.7	78.6
East – SMEs	76.8	73.4	65.1	60.3	72.2	69.5
Central – Large	78.7	76.1	69.6	65.2	75.2	73.1
Central – SMEs	70.3	68.8	58.5	55.6	68.4	64.3
West – Large	74.5	72.7	63.4	60.1	71.6	68.5
West – SMEs	66.6	63.2	52.8	49.4	64.7	59.3
Overall mean	75.2	72.6	64.3	60.5	72.1	68.8

As revealed in **Table 2**, a clear interaction effect is observed between region and firm size: enterprises in eastern regions and large firms consistently lead in tool proficiency and collaborative capability, with these advantages becoming more pronounced in higher-order competencies such as automation scripting and model interpretation. A hedged test of the DLI against defect rates (measured in per million parts, PPM) indicates that a 10-point increase in DLI corresponds to an approximate 8.3% reduction in median PPM. After controlling for equipment aging and production lot size, the effect remains statistically significant ($P < 0.05$), suggesting that enhanced digital literacy contributes to quality stability by improving process visibility and accelerating operational decision-making.

3.3. Professionalism and cross-boundary collaboration

In complex, human-machine integrated organizational environments, the efficacy of technical value realization is critically shaped by professionalism and the quality of collaborative interactions. To systematically assess these competencies, a Professionalism & Collaboration Index (PCI) is constructed, incorporating five measurable dimensions: safety and risk awareness, quality responsibility, communication and team mechanisms, cross-domain learning and knowledge sharing, as well as problem closure and continuous improvement (**Table 3**). This index further enables the analysis of elasticity between training investment and corresponding performance enhancement.

Table 3. PCI and training-output elasticity

Indicator	Weight	Sample mean	Marginal effect of +10% training
Safety compliance & risk awareness	0.20	82.3	Workplace incidents ↓ 6.2%
Quality responsibility & traceability	0.20	78.8	Rework rate ↓ 5.3%
Communication & team mechanisms	0.20	76.4	Handover errors ↓ 7.1%
Cross-domain learning & sharing	0.20	74.2	New-process rollout time ↓ 8.6%
Problem closure & continuous improvement	0.20	73.5	Defect recurrence ↓ 9.1%
PCI (weighted)	-	77.2	OEE elasticity +1.8 pct

Table 3 demonstrates significant improvements in key operational metrics across all sub-dimensions of the PCI. Among these dimensions, problem closure & continuous improvement exert the strongest marginal pull on reducing defect recurrence—this finding provides empirical evidence that under the new quality productivity paradigm, process discipline and collaboration mechanisms serve as the critical hub connecting technology, organization, and performance. Furthermore, quantile regression results reveal that for firms falling within the bottom 25% of baseline performance, every 10-point increase in the "communication & team mechanisms" sub-dimension leads to an improvement in OEE that is nearly 1.6 times that of top-quartile firms. This suggests that organizations with weaker managerial foundations possess greater room for performance improvement through targeted interventions.

Three consistent conclusions are derived from the analysis. First, the CSI exhibits a statistically significant association with productivity. This confirms that the integration of engineering understanding, data capability, and green awareness constitutes a universal driver of both operational efficiency and product quality. Second, the DLI exerts a robust influence on quality stability, with automation scripting proficiency and model comprehension emerging as key differentiators between higher-tier and lower-tier talents. Third, the PCI translates technical potential into sustainable process improvements through the organizational mechanism

of "communication–standards–closure." Collectively, these findings imply that talent development initiatives should not only prioritize the enhancement of technical competencies but also concurrently invest in data intelligence and organizational collaboration capabilities. To align with the demands of new quality productivity, it is essential to establish a closed-loop system encompassing capability profiling, curriculum design, on-the-job training, and performance feedback.

Building on the firm-level data utilized in this study, future research can advance this line of inquiry in two key directions: first, by applying causal identification methods (e.g., instrumental variable estimation, regression discontinuity design) within the established indicator framework to address endogeneity concerns; second, by conducting cross-industry benchmarking to validate the generalizability of the findings. Such extensions would generate evidence with stronger external validity, thereby providing more actionable insights for policy formulation and vocational education pedagogy.

4. Current status and challenges of the skilled-talent training system

The current skilled-talent training system, mainly school-driven with alternating classroom and practical sessions, struggles to keep pace with the rapid technological and structural changes in new quality productivity.

Curriculum and resource lag: Curriculum standards and textbooks are outdated, failing to reflect industrial advancements. Many majors still focus on traditional equipment and processes, lacking crucial modules on the industrial internet, intelligent sensing, digital twins, and green manufacturing. This leads to graduates requiring extensive retraining upon entering the workforce.

School-enterprise cooperation shortcomings: School-enterprise cooperation is often superficial, limited to internships and equipment donations. Enterprises rarely engage deeply in program design, course co-development, project-based teaching, or formative assessment. Authentic production data and real-world industrial scenarios seldom reach the classroom, creating a disconnect between practical training and actual shop floor conditions.

Facility and faculty mismatches: Facilities in some institutions are outdated, with long refresh cycles and low digitalization levels, misaligned with enterprise production lines. This inadequacy hampers training in flexible manufacturing, data-driven quality control, and human-machine collaboration. The number and utilization of industry-education integrated bases vary widely, exacerbating regional and institutional disparities. Faculty structures also fail to meet the demand for composite talents. The proportion of "dual-qualified" teachers is low, and mentors with a blend of engineering, data analytics, and green compliance skills are scarce. Enterprise adjunct mentors face participation barriers due to appraisal and incentive issues. Mechanisms for teacher in-plant secondments and incorporating engineering projects into courses are underdeveloped, hindering integrated training.

Evaluation and governance gaps: Evaluation and certification rely heavily on one-off exams and skill licenses, lacking process metrics and portfolio evidence for innovation, digital literacy, and collaboration. Stackable credits and credentials between academic and occupational qualifications are scarce, impeding learning outcomes. Lifelong learning ecosystems and learning account systems are underdeveloped. Benefit-sharing and risk-sharing mechanisms in industry-education collaboration are incomplete, with uneven implementation of incentives. Regional disparities in educational resources, industrial clusters, and platform capabilities hinder case replication. Data use in teaching is constrained by privacy and intellectual property issues, lacking standardized de-identification and sandbox mechanisms.

Rising standards and implementation bottlenecks: Increasing green and safety standards raise the bar for energy efficiency and occupational health, yet relevant coursework and drills are limited. Students often memorize rules without practical decision-making experience. Funding and organizational capacity are bottlenecks, with underinvestment in digital platforms and virtual simulation. Post-project maintenance and content refresh lag, creating a "build fast, use briefly" cycle.

In conclusion, the skilled-talent training system faces challenges of outdated content, shallow school-enterprise cooperation, faculty-evaluation mismatches, governance and data gaps, and uneven resource distribution. This results in a misfit between training and job requirements, leaving students ill-prepared for technology, data, and green-constrained work environments. To align talent supply with new quality productivity, the system must advance in content, faculty, scenarios, evaluation, and governance, rebuilding curricula around industry needs, strengthening dual-qualified teaching, adopting data-driven evaluation, opening school-enterprise boundaries, and scaling high-quality resources.

5. Innovative training paths for highly skilled talent oriented to new quality productivity

Training pathways should be restructured based on a technology-data-sustainability triad, integrating foundational courses, core technical skills, and industry-specific projects along the industrial value chain. Courses must be grounded in real-world scenarios, guiding learners through need identification, solution design, parameter tuning, and outcome assessment to convert theoretical knowledge into actionable processes.

Industry-education collaboration should advance from resource sharing to joint governance and standardization, establishing a hybrid virtual-physical practice ecosystem via industry-academia partnerships, shared labs, and on-site apprenticeships. Faculty exchanges with enterprises and engineer-led campus instruction foster a continuous loop of teaching, production optimization, and pedagogical enhancement.

Practical training must incorporate digital twins, data analytics platforms, and AI-driven tutoring for risk-free experimentation and data-based performance refinement. Assessment methods should shift to competency-based evidence chains, systematically collecting portfolios and processing data linked to CSI, DLI, and PCI metrics. Credits and credentials should enable cross-system portability and mutual recognition.

Sustainable implementation requires institutional frameworks with dual-track faculty advancement, enterprise mentor incentives, and specialized platform management. Data security can be ensured through multi-layered anonymization and controlled testing environments. Modular micro-credentials and short programs should support adaptive, job-embedded lifelong learning, enhancing career adaptability in evolving economic contexts.

6. Case analysis and path practice

Taking "Plant A of a Suzhou intelligent-manufacturing enterprise" as a case study, the plant initiated a composite training approach on its assembly and machining lines in June 2025, integrating digital twins, a data platform, and AI-driven tutoring. Collaboratively, it established an enterprise-mentor system and on-site apprenticeship stations with a partner college. Significant improvements in key performance indicators were observed: OEE increased from 61–64% (January to May) to 76% by December; the defect rate PPM decreased from 920 to 640; and energy consumption per standard labor hour dropped from 4.30 kWh to 3.62 kWh. These outcomes align with the technology-data-green tri-driver framework, demonstrating that real-world tasks and a closed data loop can translate individual skill enhancements into process stability and operational resilience.

To elucidate the "people-technology-system" linkage with production line performance, we constructed three indices—CSI, DLI, and PCI—across four key departments. As illustrated in **Figure 2**, machining and assembly lead in CSI (78, 76), while QA excels in DLI and PCI (76, 79). Maintenance demonstrates relatively lower scores (71, 68, 73). Correlation analysis reveals that engineering comprehension and process optimization in upstream/midstream roles drive efficiency gains, whereas enhanced quality assurance and collaboration mechanisms improve stability through systematic defect resolution and standardization. Departments with superior index performance contributed most significantly to OEE improvement, aligning with the trend of rising normalized OEE alongside declining PPM and energy intensity in **Figure 3**.
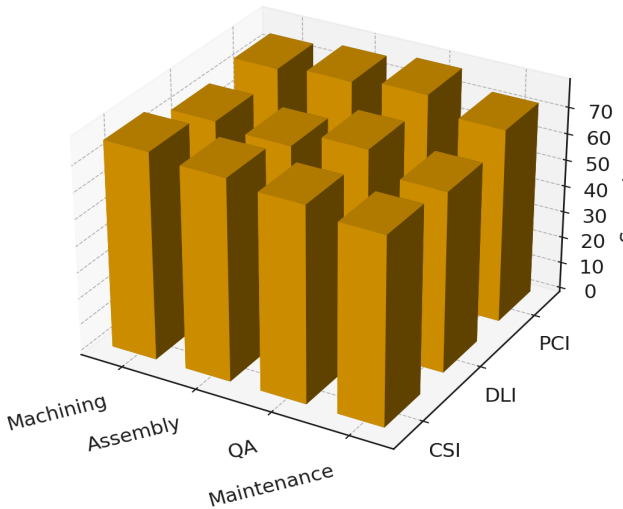
Figure 2. 3D bar chart of departmental capability indices
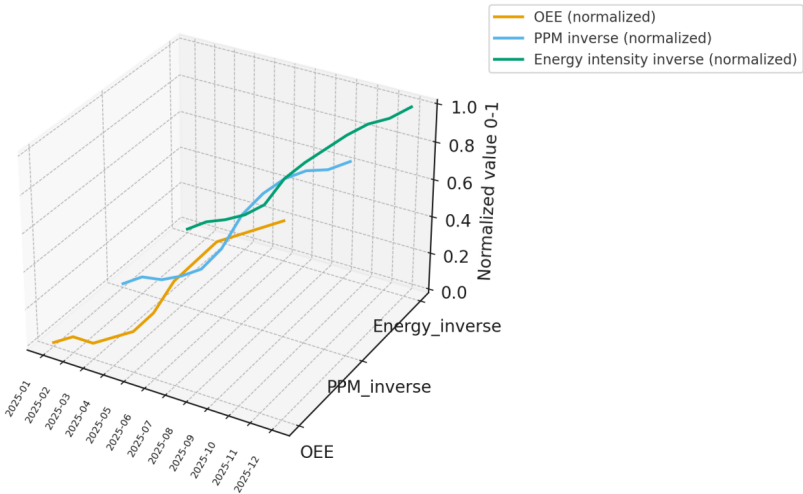
Figure 3. 3D line chart of normalized monthly trends for OEE/PPM/energy in 2025

The implementation was structured around three parallel approaches. First, course–project isomorphism transformed real production challenges—including assembly takt time variation, tool-life prediction, and WIP quality control—into classroom projects. These were analyzed through digital twins using sensitivity testing and A/B testing before progressing to small-lot validations and line feedback. Second, joint governance enabled

enterprises to provide anonymized work orders and equipment logs, while schools and firms co-developed competency rubrics and credential packages recorded in learning accounts for career advancement. Third, process evaluation established evidence chains through CSI/DLI/PCI metrics—including simulation logs, operational traces, and quality improvement curves—linking learning activities to performance outcomes.

After six months, OEE improvements primarily resulted from reduced changeover times and fewer unplanned stoppages. Defect rate reduction was mainly driven by decreased recurrence of known issues, while energy savings were achieved through optimized standby strategies and parameter tuning. This case demonstrates that institutionalizing data accessibility, co-standardization, and two-way faculty-engineer mobility enables composite training pathways to deliver measurable, synchronized gains in quality, efficiency, and sustainability within six months.

7. Conclusion

In the context of new quality productivity, this study delineates the competency profile of highly skilled talent, encompassing engineering acumen, data intelligence, green compliance, and collaborative capacity. It identifies critical bottlenecks in current training systems, such as outdated content, superficial industry-education collaboration, and flawed evaluation methods. The proposed solution emphasizes deep industry-education integration, digital twin and data platform utilization, process-evidence-based assessment, and lifelong learning. The Suzhou case validates the approach, showing simultaneous improvements in quality, efficiency, and energy performance. Given limitations in sample scope and duration, future research should explore cross-industry benchmarking, causal analysis, and policy impact assessment.

Disclosure statement

The authors declare no conflict of interest.

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