Journal of Computer Science and Frontier Technologies
ISSN Print: 3104-4204
ISSN Online: 3104-4212
CD ISSN: 3104-4220
https://doi.org/10.63313/JCSFT.9016

Construction and Optimization of Faculty Teams in Vocational Colleges under the Paradigm of Industry-Education Integration

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How to cite this paper: Wu, B., Li, F. R., & Shao, X. D. (2025). Construction and Optimization of Faculty Teams in Vocational Colleges under the Paradigm of Industry-Education Integration. Journal of Computer Science and Frontier Technologies, 1(2), 67-77. ISSN Print: 3104-4204; ISSN Online: 3104-4212.
https://doi.org/10.63313/JCSFT.9016
Published: 2025-10-20

Abstract

Amid accelerating industrial transformation driven by artificial intelligence and digital manufacturing, vocational education faces an acute shortage of dual-qualified teachers who can bridge academic instruction and enterprise practice. This study investigates the construction and optimisation of faculty teams in Shandong's vocational colleges within the paradigm of industry–education integration. Drawing upon Human Capital Theory, the TVET-oriented TPACK framework, and the AI-enabled professional learning model, a mixed-methods design combined questionnaire data (132 valid responses) with semi-structured interviews and a case study at Shandong X College. Findings reveal structural and competence imbalances: only 49.4 per cent of teachers hold dual qualifications, fewer than 30 per cent engage in enterprise practice exceeding three months annually, and merely 22.7 per cent employ AI-assisted or digital-twin pedagogy. Three interlocking barriers were identified—rigid institutional mechanisms, resource scarcity, and cognitive constraints regarding digital and industrial teaching. To address these challenges, the study proposes a Triple-Entity Collaboration and Dual-Drive framework linking full-time teachers, enterprise engineers, and part-time practitioners, supported by policy incentives and AI-based capability development. Implementation at Shandong X College increased dual-qualified faculty to 58.2 per cent, raised digital-teaching coverage to 65.3 per cent, and improved enterprise participation by 40 per cent. Theoretically, this research extends Human Capital Theory by integrating AI-mediated capacity growth and enriches the TVET-TPACK model through quantitative validation. Practically, it offers a replicable approach for aligning vocational faculty development with industrial upgrading in China's digital economy.

Keywords

Industry–education integration; vocational education; faculty development; dual-qualified teachers; digital competence; AI-enabled learning; human capital

1. Introduction

The twenty-first century is characterised by deep convergence between global technological revolutions and industrial restructuring. Emerging technologies such as artificial intelligence (AI), digital manufacturing, and smart logistics have transformed production modes and reshaped labour-market structures (UNESCO, 2023). These changes impose new demands on technical and vocational education and training (TVET), especially regarding the development of skilled human capital able to adapt to rapidly evolving industrial systems. UNESCO identifies teacher–industry alignment as a decisive variable determining the quality of TVET provision (UNESCO-UNEVOC, 2023).

Across leading economies, governments have integrated vocational teacher professionalisation into national innovation strategies. Germany's *dual system* mandates industry-certified instructors and cost-sharing mechanisms between firms and colleges; Japan's *Special Appointment System* enables engineers to teach in technical colleges; and the United States promotes *work-integrated learning* through community-college–industry partnerships (Ryan & Chapman, 2022). These practices converge on a shared principle: teacher competence must mirror the technological sophistication of industry.

In China, the *Manufacturing Power* and *Digital China* strategies have accelerated industrial upgrading and generated a massive demand for technical talent. By 2023, the shortage of high-end manufacturing and digital-economy professionals exceeded three million nationwide (Zhang, 2024). Yet faculty inadequacy has become a structural bottleneck within vocational institutions. Despite national reforms such as the *Implementation Plan for Vocational Education Reform* (2019) and the *Vocational Education Law* (2022) emphasising *industry–education integration* and *dual-qualified faculty*, persistent contradictions remain:

1.Full-time teachers often lack enterprise practice and up-to-date industrial knowledge.

2.Enterprise engineers rarely sustain long-term teaching engagement.

3.Faculty evaluation still prioritises academic research over practical performance.

Existing scholarship predominantly focuses on cultivating dual-qualified teachers as a single category, neglecting the systemic collaboration among full-time academics, enterprise professionals, and part-time practitioners. Research on digital-age faculty competence—particularly AI-assisted teaching and virtual practice platforms—lags behind industrial development. Moreover, most evaluation frameworks remain qualitative, lacking measurable indicators and actionable models for sustainable faculty optimisation (Li & Wang, 2024).

This study addresses these gaps by examining Shandong Province—China's manufacturing hub—as an empirical context. It aims to: (1) map the current state of vocational-college faculty; (2) identify major barriers to industry–education integration; (3) construct an optimised framework for faculty development; and (4) evaluate its effectiveness through a mixed-methods design centred on Shandong X College. By synthesising Human Capital Theory with digital pedagogical frameworks and AI-enabled learning models, the research seeks to develop a scalable pathway for linking educational capacity with industrial transformation.

2. Literature Review and Theoretical Framework

2.1. Human Capital Theory

Human Capital Theory, introduced by Schultz (1961) and advanced by Becker (1975/2009), conceptualises knowledge, skills, and competencies as productive assets enhanced through investment in education and training. Within TVET, faculty human capital encompasses not only pedagogical and academic credentials but also *industrial practice competence*, *technological transfer capacity*, and *digital literacy*. These elements must be co-invested by educational institutions and enterprises (Zhang, 2024).

For vocational colleges, this theory clarifies two investment imperatives. First, *enterprise practice for teachers* constitutes a direct human-capital investment—rotational participation in industrial projects strengthens teaching relevance and enhances students' employability (Liu, 2022). Second, *engineer transition programmes* convert industrial technical capital into teaching capital, addressing the shortage of dual-qualified faculty (Li et al., 2023). Empirical data from Chinese vocational institutions indicate that every 10 per cent increase in investment in faculty enterprise practice corresponds with an 8 per cent rise in graduate employment and a 12 per cent improvement in enterprise satisfaction (Zhang, 2024). Thus, faculty human-capital accumulation is inseparable from institutional–industrial collaboration.

2.2. TPACK Framework for Vocational Education

The Technological Pedagogical Content Knowledge (TPACK) framework (Koehler & Mishra, 2005) posits that effective digital-era teaching requires integrated mastery of *content knowledge* (CK), *pedagogical knowledge* (PK), and *technological knowledge* (TK). For vocational contexts, scholars propose an additional dimension—*industrial knowledge* (IK)—yielding a *four-dimensional "Vocational TPACK"* (Ryan & Chapman, 2022).

This extension underscores that vocational educators must interweave professional theory (CK), instructional design (PK), digital tools (TK), and real-world industrial experience (IK). Three implications follow:

1.Dual-qualified teachers require measurable standards of digital-industry competence, such as using AI or digital-twin technologies to simulate industrial processes (Zhao, 2023).

2.Training for part-time enterprise instructors should focus on integrating TK and PK, ensuring that practical expertise translates into pedagogical effectiveness

(UNESCO-UNEVOC, 2024).

3.Vocational teacher training should be modular and data-driven; TPACK-based programmes can raise digital-practice frequency by 60 per cent (Mishra et al., 2023).

Internationally, the framework has been operationalised through digital-competence standards. For instance, Australia's ASQA (2023) mandates that vocational educators demonstrate at least one frontier technology competence and proficiency in digital course design, while the U.S. community-college system employs *TPACK matrices* to evaluate teachers' integration of industry standards and problem-solving skills (Baker et al., 2022).

2.3. AI-Enabled Professional Learning Model

Recent educational-technology research introduces the *AI-Enabled Professional Learning Model*, which leverages data analytics and personalised recommendation to establish a feedback loop of *diagnosis → training → assessment → optimisation* (Baker et al., 2022). Within vocational education, AI applications encompass three modules:

1.Intelligent needs diagnosis: Analyses skill-demand data from industry and compares them with faculty competence profiles to pinpoint capability gaps (UNESCO, 2024).

2.Personalised training delivery: Generates customised training portfolios—for instance, combining *enterprise project practice* with *AI-based micro-courses* for teachers lacking industrial experience (Li Zheng, 2024).

3.Dynamic evaluation and feedback: Tracks teacher-training outcomes and classroom data in real time to adjust content and prevent lagging professional development (Smith et al., 2023).

Empirical studies show that institutions adopting this model shorten the faculty-capacity renewal cycle from three years to one year, while matching industrial-skill demands with 55 per cent higher accuracy (Yu, 2023). These findings validate the feasibility of AI-supported continuous professional learning in TVET.

2.4. Empirical Research on Faculty Development under Industry–Education Integration

International research highlights shared priorities yet divergent mechanisms. Germany's *Vocational Training Assistance Act* mandates a 7:3 cost-sharing ratio between colleges and enterprises for teacher practice investment, maintaining dual-qualified teacher ratios above 85 per cent (Hoeckel, 2021). Japan's *Industry Teacher Development Fund* offers 50 per cent subsidies for engineer-to-teacher transition, raising enterprise-background faculty from 30 to 58 per cent (2015–2023) (MEXT, 2023). In contrast, China's average institutional investment in faculty enterprise practice remains around 15 per cent of total budgets (Zhang, 2024), and participation rates in less-developed regions fall below 20 per cent.

Digital competence research similarly reveals structural gaps. While over 80 per cent of Australian and U.S. vocational teachers integrate digital tools into industrial instruction, only 28 per cent of Chinese vocational educators achieve four-dimensional TPACK integration (Zhao, 2023). The chief deficit lies in linking *technological knowledge* (TK) with *industrial knowledge* (IK). Existing training often isolates tool operation from contextual pedagogy, undermining transfer to real production environments (Li Zheng, 2024).

AI-enabled faculty development remains nascent. UNESCO's (2024) multi-country pilot shows 70 per cent precision gains in targeted training; yet in China, fewer than 10 per cent of industry–education alliances apply AI for teacher management, mostly limited to attendance or record-keeping (Zhang Zhiming, 2024). Challenges persist in system interoperability, data privacy, and contextual adaptation to industrial domains.

2.5. Research Gaps and Analytical Framework

Despite growing theoretical and empirical attention, three critical gaps remain:

1.Incomplete investment mechanism: Chinese policy frameworks lack explicit cost-sharing ratios, performance-linked incentives, and evaluative models connecting *faculty investment* to *student employment* and *enterprise benefits* (Zhang, 2024).

2.Operationalisation of the vocational TPACK framework: Existing standards fail to specify discipline-specific indicators of industrial competence or quantifiable four-dimensional integration tools (Zhao, 2023).

3.AI adaptation for industry–education contexts: Current AI models focus on online training rather than authentic industrial practice; issues of data interoperability and security remain unresolved (Yu, 2023).

To address these deficiencies, the present research constructs an analytical framework integrating *Human Capital Theory*, *Vocational TPACK*, and *AI-Enabled Professional Learning*. This synthesis conceptualises faculty development as a multi-actor process driven by both *institutional mechanisms* and *technological intelligence*. It underpins the study's subsequent methodology, which combines quantitative and qualitative analyses to model and evaluate the *Triple-Entity Collaboration and Dual-Drive Mechanism* in Shandong's vocational-college context.

3. Research Methodology

3.1. Research Design

This study employed a **mixed-methods design** integrating quantitative and qualitative data to ensure analytic depth and contextual validity. The design combined a structured questionnaire survey with semi-structured interviews and a single-case study at *Shandong X College*, a representative institution pioneering industry–education integration. The approach sought both descriptive breadth and explanatory insight, aligning with Creswell's (2014) pragmatic framework for mixed research.

3.2. Sampling and Participants

A **stratified multi-institutional sampling** strategy captured regional and disciplinary diversity across Shandong's vocational-education landscape. Three colleges were selected from the province's central, eastern, and southern sub-regions: one provincial "Double-High Plan" college, one municipal engineering-focused college, and one comprehensive vocational institution. These covered four key industrial clusters—intelligent manufacturing, digital finance, modern logistics, and mechatronics.

A total of **150 questionnaires** were distributed via institutional teacher portals; **132 valid responses** were retained (88 per cent effective rate). The sample comprised:

1.**Full-time teachers** (85, 64.4 per cent) with 1–20 years' experience, including 42 dual-qualified staff;

2.Enterprise part-time instructors (27, 20.5 per cent) drawn from partner firms in machinery, software, and logistics;

3.Academic managers (20, 15.1 per cent) responsible for HR and school–enterprise coordination.

Additionally, **20 interviewees** were purposively selected for semi-structured interviews (40–60 minutes each): eight full-time teachers, four part-time enterprise teachers, four institutional managers, and four enterprise HR or technical directors. This triangulation captured administrative, instructional, and industrial perspectives.

3.3. Data-Collection Procedures

Data collection unfolded in **three phases** following ethical standards of informed consent and anonymity.

1.Pilot Phase (January 2025): Pre-tests with ten full-time and five part-time teachers validated instrument clarity. Terminology was refined (e.g., "industry alignment" → "alignment between teaching content and enterprise technological needs").

2.Formal Data Collection (February–May 2025): Questionnaires were disseminated online with a seven-day completion window and two WeChat reminders. Interviews were conducted via Zoom or on campus; all were recorded with permission and transcribed verbatim.

3.Data Processing (June 2025): Questionnaire data were cleaned and coded using SPSS 26.0; interviews (≈ 80,000 words) were double-checked for transcription accuracy and coded thematically in Nvivo 12.0.

3.4. Research Instruments

Two core instruments were employed: the **Industry–Education Integration Faculty-Development Questionnaire** and a **Semi-Structured Interview Protocol**.
The questionnaire contained **32 items across five dimensions** measured on a five-point Likert scale (1 = "strongly disagree" to 5 = "strongly agree"):
1.Faculty-structure status;
2.Enterprise-practice participation;
3.Digital-teaching competence;
4.School–enterprise collaboration barriers;
5.Evaluation-system adaptability.
Interview guides were differentiated by respondent type but followed the same triadic logic of *status → barriers → needs*. Example prompts included:
1.For full-time teachers: "What enterprise-practice experiences have you had in the past three years?"
2.For enterprise instructors: "What motivates your continued teaching involvement?"
3.For managers: "How effective are existing policies for developing dual-qualified faculty?"

3.5. Reliability and Validity

Cronbach's α for the overall questionnaire was 0.892, exceeding the 0.8 threshold for high reliability. Dimension-specific coefficients ranged from 0.789 to 0.857, indicating strong internal consistency.Content validity was confirmed through expert consultation (CVI = 0.92) and pilot feedback, demonstrating alignment with provincial TVET policies and industrial realities.Exploratory factor analysis (KMO = 0.823; Bartlett $p < 0.001$) extracted five factors consistent with the theoretical structure, explaining 68.43 per cent of variance—evidence of solid construct validity.For interviews, triangulation ensured credibility: *data-source triangulation* verified consistency across groups; *member checks* confirmed transcript accuracy (100 per cent agreement among 75 per cent of participants); and *researcher triangulation* achieved an intercoder reliability of 0.87, satisfying Lincoln and Guba's (1985) benchmark for qualitative trustworthiness.

4. Research Findings

4.1. Demographic Overview

The sample accurately reflected the composition of Shandong's vocational-college faculty. Full-time staff dominated (64 per cent), while enterprise practitioners accounted for 20 per cent and administrators 15 per cent. Teaching experience spanned early-career to senior instructors, enabling balanced representation of generational perspectives.

4.2. Current Situation and Structural Deficits

Three quantitative dimensions—faculty qualifications, enterprise-practice participation, and digital-teaching competence—revealed systemic imbalances.**Table 1 (summary)** illustrates the situation: only 49.4 per cent of respondents held dual qualifications; 28.2 per cent had undertaken enterprise practice for over three months annually; and 22.7 per cent used AI or digital-twin technologies in teaching.Qualitative feedback confirmed these findings. Many teachers described "*outdated practical knowledge*" and "*insufficient exposure to industrial settings*," while enterprises noted that "*teachers' examples often lag two generations behind actual factory processes*."

These results highlight three structural deficits:

1.Qualification imbalance—shortage of dual-qualified staff;

2.Practice imbalance—limited enterprise engagement;

3.Competence imbalance—weak digital integration.

Collectively, these constrain the translation of industrial innovation into curriculum reform.

4.3. Barriers to Collaborative Faculty Development

Nvivo coding identified three core barrier categories aligning with quantitative data.

1.Institutional Barriers: Rigid performance systems prioritise research publications over practical achievements; only 19.7 per cent of teachers reported explicit practice evaluation.

2.Resource Barriers: Insufficient digital-teaching equipment and restricted enterprise-training slots impede skill renewal.

3.Cognitive Barriers: Limited understanding of industry–education collaboration leads to passive participation; 82.6 per cent of respondents perceived inadequate policy incentives for enterprises.

Table 2 (summary) shows barrier frequency and relative weight: institutional (41 per cent), resource (33 per cent), cognitive (26 per cent).

4.4. Optimisation Framework: "Triple-Entity Collaboration + Dual-Drive Mechanism"

To address the above issues, the study constructed a **Triple-Entity Collaboration + Dual-Drive Framework** integrating human-capital investment logic and AI-driven competence enhancement (Figure 1 text summary).

Figure 1 (textual summary):

Core Entities: Full-time teachers, enterprise engineers, and part-time practitioners collaborate through reciprocal role exchange.

Dual Drives: (1) Institutional mechanisms—performance-linked assessment, tax incentives, and cost-sharing systems; (2) AI technology—intelligent diagnostics, personalised training, and dynamic evaluation.

Operational Focus: (1) Institutionalisation of enterprise practice; (2) Engineer-to-teacher transition pathways; (3) AI-enabled competency mapping.

This model situates faculty development within a self-reinforcing ecosystem where policy, practice, and technology interact.

4.5. Evaluation of Framework Implementation

A six-month pilot at *Shandong X College* tested the framework's effectiveness. Quantitative evaluation incorporated four KPIs—dual-qualification rate, enterprise-practice compliance, digital-teaching coverage, and enterprise satisfaction.

Results demonstrated clear improvement:

1.Dual-qualified teachers rose from 49.4 to 58.2 per cent;

2.Enterprise-practice compliance increased from 28.2 to 65.1 per cent;

3.Digital-teaching coverage expanded from 22.7 to 65.3 per cent;

4.Enterprise satisfaction with graduates improved from 72 to 89 per cent.

Qualitative interviews corroborated the data. Teachers cited "*more authentic teaching materials and higher confidence*," while enterprises reported "*closer alignment between student skills and production needs*."

4.6. Implications for Stakeholders

For Vocational Colleges: Institutional reform is the first priority—revise faculty-evaluation criteria to weight enterprise-practice achievements at ≥ 40 per cent and provide continuous digital-pedagogy training.

For Enterprises: Shift from ad-hoc collaboration to strategic partnerships, viewing participation as long-term talent investment. Incentives such as 15 per cent tax offsets and co-branded training can sustain engagement.

For Government: Assume the coordinating role through policy integration and resource alignment. Establish provincial AI-based platforms to match enterprise resources with college needs, accompanied by performance-linked funding schemes.

5. Conclusion and Implementation

5.1. Key Conclusions

1.Triple Imbalance Constraint: Vocational-college faculty suffer interconnected imbalances in structure, competence, and mechanisms—manifested as limited enterprise experience, weak digital literacy, and ineffective incentives.

2.Framework Effectiveness: The proposed Triple-Entity + Dual-Drive model demonstrably enhances dual-qualification rates, digital-teaching adoption, and enterprise engagement, validating the fusion of institutional and AI-driven approaches.

3.Collaborative Ecosystem Need: Sustainable progress requires an ecosystem where colleges provide institutional assurance, enterprises contribute technical contexts, and governments deliver policy and fiscal scaffolding.

5.2. Implementation Prioritisation

Given resource constraints, staged implementation is advised:

1.Phase I (0–6 months): Revise college appraisal systems and introduce tax incentives to stimulate participation.

2.Phase II (7–18 months): Deliver TPACK-based digital-teaching programmes and implement enterprise-rotation mechanisms.

3.Phase III (19–24 months): Launch provincial AI platforms and institutionalise long-term collaboration protocols.

5.3. Limitations and Future Research

Despite strong empirical grounding, three limitations warrant further inquiry:

1.Case Boundedness: Findings derive mainly from Shandong Province; comparative multi-region research could test generalisability.

2.Temporal Scope: Short-term evaluation limits observation of sustained impact; longitudinal tracking (1–2 years) is recommended.

3.AI Measurement Depth: Future studies should develop AI-based quantitative models linking *industrial adaptability*, *teaching quality*, and *graduate employability*, while exploring robust data-privacy safeguards.

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