

A Digitally-Driven Three-Stage Progressive and Cross-Module Collaborative Talent Cultivation Model for Vocational Undergraduate Computer Programs

Hailing Xiao*

Guangzhou Vocational University of Science and Technology, Guangzhou, 510550, China

xiaohailing@gkd.edu.cn

**Corresponding author*

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Abstract: The continuous upgrading of capability requirements for computer technology talents driven by enterprise digital transformation has created a dual dilemma for vocational undergraduate computer graduates in the job market: widespread job-seeking difficulties and low job adaptability. To address this supply-demand mismatch, this study conducted field visits and questionnaire surveys across 5 vocational undergraduate institutions and 20 digitally transforming enterprises, identifying three critical adaptability gaps between the two sides. It was also found that the fragmentation of the curriculum system, caused by the separation of multiple computer specialization tracks, further exacerbates this supply-demand contradiction. Building upon this analysis, the study proposes a framework of "demand-driven, collaborative co-construction, and dynamic feedback," and constructs a three-stage progressive collaborative talent cultivation model featuring "one core project + N directional modules + cross-module linkage." Four specific implementation pathways are designed accordingly. Two-year pilot data demonstrates upward trends in students' skill assessments and practical capabilities, targeted employment and retention rates, as well as enterprise satisfaction with graduates' technical competencies. The findings can also serve as a reference for the reform of practical teaching systems in computer programs across various institutions.

1. Introduction

According to the China Digital Economy Development Research Report released by the China Academy of Information and Communications Technology, China's digital economy reached 59.2 trillion yuan in 2024, accounting for 43.8% of GDP [1]. Over 60% of enterprises identify the shortage of digital-skilled talent as a primary challenge in the digital transformation process [2-3], a gap that vocational undergraduate computer education is uniquely positioned to address. Following the launch of pilot programs for undergraduate-level vocational education in 2019, relevant policies have continued to advance the development of vocational undergraduate education [4]. Currently, vocational undergraduate computer programs generally adopt a "foundation plus incremental

specialization" model, dividing curricula into multiple independent tracks—such as embedded systems, front-end development, network security, and big data—to accommodate diverse industry demands. However, these tracks operate in isolation with limited integration, resulting in fragmented knowledge systems among students, inadequate comprehensive project-based practical skills, and significant difficulty in cultivating interdisciplinary talent. Moreover, existing vocational undergraduate computer education remains anchored in traditional frameworks centered on programming and hardware maintenance, while competencies required for digitalized roles—such as low-code development and data platform operations—have yet to be systematically incorporated into curricula. Enterprise-side digital talent development largely relies on post-employment training, failing to establish effective articulation with vocational undergraduate training cycles.

This study focuses on three objectives: first, to identify specific gaps between computer specialty talent cultivation and enterprise digital transformation demands; second, to construct a theoretical framework for school-enterprise collaborative talent cultivation; and third, to propose implementation pathways for this model within vocational undergraduate computer education.

2. Adaptability Analysis of Vocational Undergraduate Computer Education and Enterprise Digital Transformation

2.1. Diagnostic Assessment of the Current State of Vocational Undergraduate Computer Education

Through investigations of five vocational undergraduate institutions offering computer programs in East China, South China, and Central China, it was found that core courses remain predominantly classical subjects such as data structures and computer organization principles, accounting for 55%–65% of required specialty courses. In recent years, some institutions have added directional courses in artificial intelligence and big data; however, these are allocated limited instructional hours (approximately 32 credit hours), focusing primarily on conceptual introduction with inadequate practical training. A more fundamental issue lies in the curricular organization: courses under each specialization track are developed and delivered independently, lacking cross-disciplinary integration [5]. Students specializing in front-end development have minimal exposure to underlying hardware, those in embedded systems possess limited knowledge of front-end technologies, and students in network security rarely engage with big data processing. With no cross-domain comprehensive practical training components across tracks, most students can only complete isolated tasks and are unable to independently undertake integrated projects requiring multi-technology collaboration. Furthermore, the average revision cycle for training programs is two years, whereas digital technologies in cloud-native computing, big data, and AI evolve approximately every 6–12 months [6]. By the time revised programs are implemented, they are already outdated, making it difficult to align with enterprises' current mainstream technology application scenarios.

In the practical teaching components of the five vocational institutions investigated, some sessions were led by instructors lacking enterprise experience, resulting in deviations from industry practice regarding project selection, technology stack decisions, and engineering standards. Project evaluation focused primarily on functional implementation, with insufficient systematic assessment of code quality, engineering workflows, and team collaboration. Training platforms predominantly employed simplified educational software versions, creating even greater gaps in core digital processes such as data collection compared to actual enterprise environments. Training data were largely artificially generated standardized datasets, lacking the noise and sparsity characteristics commonly present in real-world data.

Although all institutions investigated have engaged in school-enterprise cooperation, their participation in deep collaborative activities—including joint curriculum development, course co-

construction, faculty exchange appointments, and laboratory co-building—remains notably limited [7]. Enterprises express concerns regarding input-output ratios, administrative burdens, and technology leakage. The rapid iteration and high coupling of digital projects further amplify these risks, as core code exposure and training investments may be exploited by competitors, thereby intensifying resistance to deeper collaboration.

2.2. Analysis of Talent Demands in Enterprise Digital Transformation

The investigation covered 20 digitally transforming enterprises spanning fintech, intelligent manufacturing, information technology services, e-commerce, smart logistics, and online education. Graduates with cloud-native development capabilities were in the most urgent demand, followed by big data processing and analysis. AI full-stack development, AI application development, and network security also received substantial attention. However, coverage and instructional depth of these five competencies in current curricula remain limited. Most enterprises identified self-directed learning and rapid adaptability as the capabilities most requiring improvement among graduates, followed by problem analysis and resolution, teamwork and cross-departmental communication, and business understanding with requirements analysis. Enterprise technical leaders indicated that technical skills can be acquired through post-employment training, whereas the willingness to engage in continuous learning, awareness of communication and collaboration, and capacity to solve complex problems cannot be developed through short-term training [8].

2.3. Supply-Demand Alignment Analysis

Structural supply-demand gaps are concentrated in three dimensions. Position-articulation discontinuity arises from the fragmentation of computer programs into multiple independent specialization tracks, each operating as a closed system according to disciplinary logic without cross-disciplinary integration. Competencies required by enterprises—such as low-code development, data visualization, and operations maintenance—demand that students integrate front-end and back-end capabilities and comprehend the complete data workflow. However, students equipped with knowledge confined to a single track struggle to satisfy enterprise demands for cross-domain technical integration. Cultivation-logic misalignment is evident in the absence of end-to-end practical training within institutions, spanning from device data acquisition through front-end presentation to operational maintenance. Students encounter fragmented knowledge points rather than developing integrated competencies. Evaluation-criterion divergence is most pronounced: enterprises assess performance through digital dashboards, whereas institutions continue to rely on disciplinary examinations.

3. Construction of a Collaborative Talent Cultivation Model under the New Ecosystem

3.1. Model Framework Construction

This study constructs an industry-education integrated talent cultivation framework of "demand-driven, collaborative co-construction, and dynamic feedback," comprising three hierarchical layers. The top layer establishes goal consensus. Institutions possess theoretical foundations but lack practical exposure, whereas enterprises possess application scenarios but lack theoretical systematization [9]; this structural complementarity forms the cooperative foundation oriented toward student development, institutional advancement, and enterprise benefit. The middle layer comprises a collaborative co-construction mechanism, wherein school and enterprise partners achieve joint investment across six dimensions: training program development, curriculum design, practical

training bases, faculty resources, instructional processes, and quality evaluation—designated as the "six-co" mechanism. The bottom layer constitutes a three-stage progressive cross-group collaborative practical teaching system, guaranteed by five-party coordination among government, institution, enterprise, instructor, and student stakeholders, translating preceding collaborative outcomes into executable instructional arrangements. Finally, a feedback loop composed of "employment tracking, satisfaction surveys, and program optimization" drives iterative updates to training programs and curricular content through data-informed decision-making.

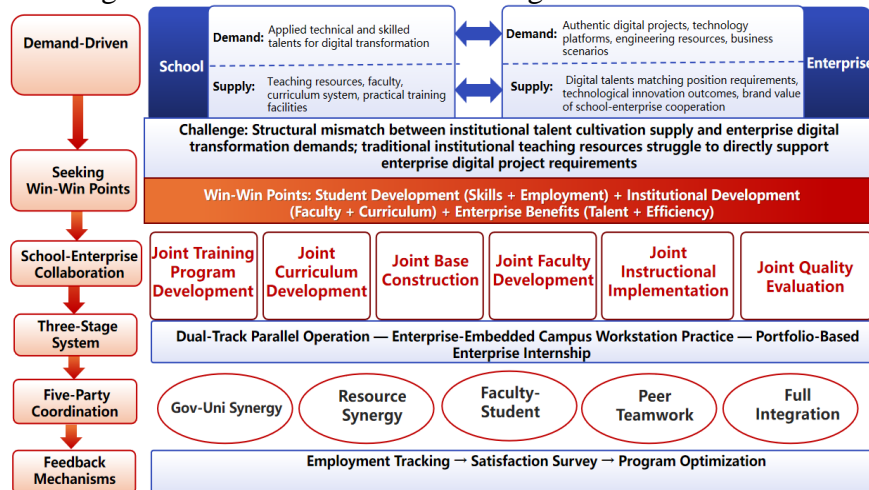


Fig. 1. Framework Diagram of the Industry-Education Integrated Talent Cultivation System

3.2. Key Mechanism Design

Based on the framework illustrated in Figure 1, the key mechanism design is elaborated across six dimensions, forming a closed talent cultivation loop through the "six-co" mechanism.

Joint Training Program Development. Capability maps are reverse-engineered from digital position requirements to inform curricular architecture, with annual micro-adjustments and biennial major revisions to dynamically incorporate emerging courses and eliminate obsolete content [10].

Joint Course Resource Construction encompasses three modalities. First, enterprise course integration, wherein internal corporate training resources are pedagogically adapted and incorporated as elective courses. Second, loose-leaf textbook design, with independent modular compilation enabling individual replacement upon technological updates without restructuring entire courses. Third, project case repositories, wherein enterprises provide de-identified authentic cases to institutions for the design of scaffolded practical training tasks.

Joint Practical Training Base Construction involves enterprises establishing digital development environments on campus with access to authentic business data, while institutions provide facilities and operational maintenance; collaborative training standards are jointly formulated.

Joint Faculty Development implements bidirectional mobility: dual-qualification faculty are dispatched to enterprise digital positions for intensive research during winter and summer breaks, while engineers with digital transformation project experience are recruited as industry mentors.

Joint Instructional Process Management assigns enterprise engineers responsibility for project-based instruction and technical review, while institutional faculty oversee theoretical foundations and learning progress tracking.

Collaborative Quality Evaluation incorporates enterprise digital talent standards; school-enterprise partners jointly design assessment protocols, with employment quality data driving reverse adjustments to training programs.

4. Implementation Pathways for the Collaborative Talent Cultivation Model

4.1. Pathway for Joint Training Program Development and Course Resource Co-Construction

The position capability map constitutes the foundational element of the entire model [11], with capability items prioritized toward digital positions. Implementation proceeds through three steps.

Step 1: Investigation. A school-enterprise collaborative team is formed comprising the institutional program director, core faculty, enterprise frontline technical supervisors, and HR personnel to conduct functional task analysis of target position clusters. Daily tasks are decomposed to reverse-engineer the knowledge, skills, and professional competencies required for each task. Capability items are calibrated across four proficiency levels—awareness, comprehension, mastery, and proficiency—with corresponding assessment criteria.

Step 2: Curriculum Mapping and Gap Filling. School and enterprise partners map capability items against existing courses; uncovered items are designated for new course development, while redundant content is consolidated. The reconstruction of the Cross-Platform Mobile Application Development course serves as an illustrative example. The original course offered only Android Application Development, which deviated substantially from the ReactNative framework employed by the enterprise; graduates from two consecutive cohorts required three months post-employment to achieve operational competency. A phased approach was adopted: the first eight weeks centered on Flutter as the core framework, delivered by institutional faculty to establish cross-platform foundations. The latter phase interfaced with enterprise mobile application projects, wherein enterprise engineers decomposed authentic requirements into independently deliverable sub-tasks for student groups. Upon completion, deliverables underwent joint debugging and deployment in the enterprise environment. A two-week transitional period was allocated between phases for students to familiarize themselves with enterprise coding standards and toolchains, addressing a real single-module problem as a warm-up exercise. Outputs from the latter phase were operational cross-platform application modules rather than complete commercial-grade production releases.

Step 3: Dynamic Curriculum Updating. Minor adjustments are conducted at each semester's conclusion to examine technological stack changes and emerging position requirements among partner enterprises. Curricular content is dynamically modified in accordance with the capability map to ensure continuous alignment between training programs and industry demands.

4.2. Three-Stage Progressive Pathway for Practical Teaching

The practical teaching system is restructured to replace the traditional semester-progress-driven model—comprising on-campus training, enterprise practice, and finally internship—with a participation-driven model based on a three-stage progressive cross-module collaborative teaching system [12]. At each stage, enterprise engineers and institutional mentors share responsibility: enterprises focus on project guidance and technical review, while institutions address theoretical knowledge gaps and learning outcome tracking, as illustrated in Figure 2.

Stage 1 (Semesters 1–4): Dual-Track Parallel Operation. The skills track involves concentrated practice two days per week, aligned with enterprise technology stack standards: code conventions follow Google Java Style, version control employs Git, and continuous integration pipelines must pass successfully. Students who pass skills track assessments advance to the project track, undertaking peripheral enterprise tasks including test case writing, documentation maintenance, and data annotation. These tasks are not complex, but immerse students in authentic project environments. Bidirectional mobility between tracks is maintained throughout: students falling behind in the skills track return for remediation, while those demonstrating rapid progress in the project track advance early to more intensive tasks. Stage 1 completion is not determined by examination scores, but by

whether students obtain micro-certifications in the skills track and leave verifiable contribution records in the project track—constituting a documented growth trajectory.

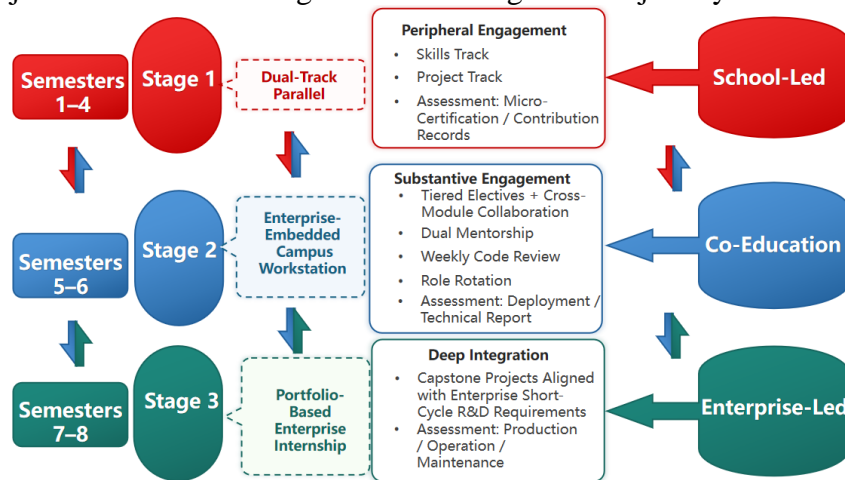


Fig. 2. Diagram of the Three-Stage Progressive Cross-Module Collaborative Teaching System

Stage 2 (Semesters 5–6): Enterprise-Embedded Campus Workstations. These workstations function simultaneously as school-enterprise co-constructed practical training bases. Students are organized into groups of four to six, operating within a collaborative talent cultivation model of "one core project + N directional modules + cross-module linkage." Enterprise digital scenarios serve as project vehicles; for example, a "Store Intelligent Customer Flow Analysis System" would engage: embedded systems students in customer flow sensor data acquisition and edge computing; network security students in data transmission link construction and transmission security assurance; front-end students in customer flow data visualization dashboard development; and big data students in customer flow data storage, real-time processing, and analytical model construction. While the four modules advance independently, rapid integration is achieved through low-code tools, with big data students finally assuming responsibility for continuous operations, monitoring, and performance tuning following system deployment. This model respects students' directional choices, enabling each student to locate their position within the project, while serializing the complete digital transformation workflow—from device acquisition and data transmission to front-end presentation and system operations—fundamentally resolving the knowledge fragmentation inherent in separate-track cultivation.

Training projects are selected from enterprise problem repositories, with enterprise engineers rotating on-site weekly to conduct code reviews. Institutional mentors track progress and address knowledge gaps. Completed projects are deployed to production where feasible; projects unsuitable for deployment require a technical report endorsed by the enterprise technical lead. Each team rotates roles every project cycle, with two cycles ensuring each student experiences development, testing, and operations. Directional identity remains fixed during role rotation: big data students assuming testing roles continue to undertake data quality validation; embedded systems students in operations roles focus on edge device monitoring—achieving parallel advancement in both directional depth and role breadth.

Stage 3 (Semesters 7–8): Enterprise Entry with Capability Growth Portfolios. Graduation project topics are aligned with enterprise short-cycle R&D requirements, sourced from concretely defined and cycle-controllable tasks within R&D plans rather than generalized directions. A position mentor is assigned from day one of enterprise entry; institutional mentors conduct collaborative assessments on-site biweekly.

Final evaluation criteria are production-oriented: task completion, functional operation, and code

maintainability. Capability growth portfolios are submitted to enterprises upon entry and returned with enterprise evaluations upon departure, thereby closing the cultivation loop.

4.3. Bidirectional Mobility Pathway for Dual-Qualification Faculty

Currently, no unified or authoritative definition of dual-qualification faculty exists, with vocational institutions varying in certification standards and specific criteria [13]. Among computer specialty faculty, the proportion with three or more years of full-time enterprise experience remains low; the majority enter teaching directly upon graduation from higher education institutions, lacking frontline industry project experience. When faculty are dispatched to enterprise postings, priority is given to digital positions to ensure the acquisition of digital competencies, with a minimum duration of six months. Priority is accorded to enterprise engineers with digital project backgrounds for institutional teaching appointments, with a minimum of 32 instructional hours per semester. Mutual recognition of workload is established: institutions retain faculty position benefits, while enterprises incorporate guidance responsibilities into performance assessments.

4.4. Multidimensional Evaluation System and Quality Assessment Pathway

The evaluation system for vocational undergraduate computer programs primarily assesses five data dimensions to examine students' proficiency in digital tool utilization and cross-system integration capabilities. The technical competency assessment protocol is co-designed by school-enterprise partners, with enterprise mentors participating in item development to evaluate students' code quality, fault localization, and vulnerability remediation capabilities. Project-based practical competency assessment is scored by senior enterprise mentors during project execution, with on-site evaluation of students' requirements review, solution design, and implementation fluency; routine code commits and communication records serve as supplementary evidence. Artificial intelligence literacy assessment primarily examines whether students can invoke large language model, image recognition, and speech synthesis API services to accomplish system integration, as well as their judgment regarding AI solution rationality. Professional competency data are sourced from enterprise internship evaluations, peer assessments, and employer feedback. Employment quality assessment focuses on job-major alignment rate, probationary retention rate, and regularization starting salary. The multidimensional data collected serve purposes beyond student evaluation; more critically, they drive reverse instructional improvement. When data in any dimension persistently fall below threshold values, corresponding review and optimization procedures are triggered.

5. Practical Effects and Discussion

5.1. Pilot Overview

This study selected Guangzhou Vocational University of Science and Technology—one of the first batch of vocational undergraduate institutions approved by the Ministry of Education—and an Internet technology enterprise as the pilot collaborators for collaborative talent cultivation. The university enrolled more than 600 students in computer-related undergraduate programs at the time of the study. To address practical challenges such as the fragmentation of specialized directions and the misalignment between talent cultivation and industrial job requirements, the university advanced the integration of industry and education through a three-phase reform initiative:

In Phase I, the university conducted industry job surveys and enterprise digital talent demand assessments, developed competency profiles for vocational undergraduate computer programs, optimized the curriculum system in alignment with enterprise employment standards, completed

revisions to specialty training programs and instructional syllabi, and finalized detailed cooperation agreements and overall implementation plans for collaborative talent cultivation.

In Phase II, the university established a two-way exchange mechanism, enabling on-campus faculty members to gain practical experience in enterprises and inviting senior enterprise engineers to deliver lectures on campus. It collaborated with industry partners to co-develop industry-tailored signature courses, integrated software and hardware resources to build a dedicated university-enterprise joint practical training platform, refined the practical training project repository and assessment evaluation standards, and established all necessary supporting facilities for practical teaching.

In Phase III, the university implemented an innovative collaborative talent cultivation model, deeply integrating real enterprise projects and operational workflows into daily teaching and practical training sessions.

5.2. Primary Achievements

School-enterprise joint assessments indicate that students' comprehensive capability scores improved by over 10%, with practical competency attainment rates increasing by more than 10 percentage points. Self-assessment scores for autonomous learning and teamwork demonstrated positive growth, while position adaptation cycles shortened by 3–5 weeks. AI literacy assessments revealed that over half of students could independently invoke AI service APIs. Employment quality indicators showed sustained improvement, with cross-directional students outperforming single-track counterparts in job-major alignment rates—validating the effectiveness of cross-module collaboration mechanisms from the employment perspective. Enterprise satisfaction tracking confirmed student recognition by employers across technical competency, teamwork, continuous learning, and business understanding dimensions. Faculty structure was concurrently optimized, with both the proportion of dual-qualification faculty and faculty with enterprise project experience increasing significantly compared to pre-pilot levels, providing instructional assurance for talent cultivation model reform.

5.3. Limitations and Deficiencies

The reform was advanced with only a small cohort of pilot students; over 600 computer specialty students did not benefit synchronously, resulting in uneven stratified cultivation and slow overall improvement in education quality. The frequency of enterprise mentor guidance fluctuated with project cycles, making quality assurance difficult during peak workload periods. Intellectual property and benefit distribution mechanisms remain undefined; ownership demarcation and revenue allocation for co-constructed courses and jointly developed cases lack institutional grounding, requiring gradual exploration and refinement in subsequent practice. While the three-stage progressive system promoted knowledge integration to some extent through cross-directional teamwork, the independent track structure at the curriculum system level persists, with some students still inclined to specialize exclusively within their own track rather than actively engaging other directions. Future efforts must further advance cross-directional course credit recognition at the training program level, establishing cross-directional elective credit mechanisms and mandatory cross-directional integrated project requirements.

6. Conclusion

The "demand-driven, collaborative co-construction, and dynamic feedback" framework proposed in this study constructs a three-stage progressive collaborative talent cultivation model featuring "one

core project + N directional modules + cross-module linkage." Two-year pilot validation has yielded positive outcomes across student capability enhancement, employment quality improvement, enterprise satisfaction increase, and faculty development. However, sustainable operation of industry-education integration cannot rely solely on voluntary participation by institutions and enterprises. Government provision of incentive policies and evaluation orientations is required; clear mechanisms for benefit distribution and risk sharing between school and enterprise partners must be established; and industry associations are well-positioned to lead standard formulation and assessment initiatives.

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