

Construction of a “School-Village-Enterprise” Collaborative Talent Cultivation Platform for Rural Areas Based on Digital Twin Technology

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ABSTRACT Talent revitalization is fundamental to sustainable rural development, yet current rural talent cultivation is constrained by fragmented educational resources, weak collaborative mechanisms, and insufficient alignment between training outcomes and practical industrial demands. As digital twin systems increasingly depend on electromagnetic information transmission, wireless sensing networks, and intelligent communication infrastructures for real-time data acquisition and virtual-physical interaction, establishing an integrated collaborative platform has become essential for precision-oriented talent development. This study proposes a “School-Village-Enterprise” collaborative talent cultivation platform driven by digital twin technology. By constructing a geospatial and socio-economic digital mirror of rural environments and integrating Internet of Things technologies, big data analytics, intelligent simulation, and multimodal data fusion, the platform enables coordinated interaction among the education chain, talent chain, industrial chain, and innovation chain. A four-layer architecture consisting of data perception, model construction, service application, and interaction interface is developed, together with a personalized learning path recommendation algorithm and dynamic digital twin updating mechanism. Practical validation demonstrates that the proposed platform improves the alignment between training content and actual rural demands from 32.7% to 73.5%, significantly enhancing collaborative cultivation efficiency while supporting adaptive decision-making in complex rural scenarios. By combining digital twin technology with electromagnetic-enabled communication infrastructures, the proposed framework provides an operational pathway for intelligent rural talent development and offers valuable references for distributed education systems and smart industrial training environments.

INDEX TERMS digital twin, collaborative talent cultivation, electromagnetic information transmission, wireless sensing network, school-village-enterprise cooperation

I. INTRODUCTION

As a major national strategy, the successful implementation of rural revitalization fundamentally relies on a large-scale, well-structured rural talent pool skilled in modern technologies. This high-quality workforce serves as the cornerstone for integrating smart manufacturing into rural economic structures, ensuring a sustainable and technologically advanced industrial foundation. However, the current rural talent cultivation system still faces multiple dilemmas: a significant gap exists between talent cultivation and the actual needs of rural areas, educational resources are extremely unevenly distributed between urban and rural areas and among different regions, and collaborative mechanisms among schools, villages, and enterprises are loose and inefficient. Traditional cultivation models often lag

behind the dynamic demands of rural industrial upgrading and governance modernization, leading to the increasingly prominent structural contradiction of “learning without application, applying without prior learning.” The 2026 topic plan of E-education Research lists “New Generation Information Technology Empowering Educational Digital Transformation” as a key focus area, providing a clear domain concern for this study[1]. In recent years, digital twin technology, as a cutting-edge technology connecting the physical and virtual worlds, has shown great potential in fields such as industrial manufacturing and urban management[2]. Driven by real-time data and high-fidelity simulation, this technology can create dynamic virtual mappings of physical entities, supporting analysis, prediction, and optimization. Introducing digital twins into the field of education, particu-

larly in the context of rural talent cultivation, offers a novel approach to overcoming the aforementioned dilemmas[3]. It can construct a virtual environment that reflects the real-time development status of rural areas, enabling the talent cultivation process to be simulated, deduced, and adjusted based on real data, thereby shifting the paradigm from “experience-driven” to “data-driven.” Concurrently, the concept of “School-Village-Enterprise” collaborative talent cultivation is gaining increasing attention[4]. Universities possess knowledge and technology, villages provide authentic scenarios and demands, and enterprises connect to markets and applications. Theoretically, collaboration among the three could form a powerful synergy. However, limited by physical space barriers, information asymmetry, and organizational silos, such collaboration often remains superficial, making deep integration and sustained benefits difficult to achieve. Therefore, constructing a digital support platform that can effectively integrate resources from all three parties and support the entire talent growth cycle has become an urgent practical issue[5].

This study aims to explore the theoretical framework and implementation pathways for the deep integration of digital twin technology and the “School-Village-Enterprise” collaborative talent cultivation model. The core question we attempt to answer is: How can digital twin technology be leveraged to construct a virtual-real integrated, dynamically adaptive, and efficiently collaborative talent cultivation platform to precisely align with rural development needs, optimize resource allocation, and systematically support the lifelong growth of rural talent? By constructing the platform model and elucidating its operational mechanisms, this study provides a practical solution for empowering rural revitalization through digitally transformed education and technology training. This framework facilitates the seamless transfer of advanced engineering knowledge, creating a forward-looking pathway for regional industrial growth through enhanced digital literacy.

II. THEORETICAL FRAMEWORK AND INTERNAL MECHANISM OF DIGITAL TWIN-ENABLED COLLABORATIVE TALENT CULTIVATION

The effectiveness of digital twins in empowering rural collaborative talent cultivation is rooted in the inherent alignment between its core characteristics—virtual-real interaction, data-driven operation, and continuous iteration—and the complex demands of rural talent cultivation[6]. A fundamental contradiction faced by traditional cultivation models lies in the disconnect between the relatively static, rigid cultivation system and the dynamically evolving real needs of rural areas. Digital twins provide a solution to this contradiction by constructing virtual copies of rural physical-social systems.

From a systems theory perspective, an ideal rural collaborative talent cultivation system should be an open, self-adaptive complex system with feedback regulation capabilities. The digital twin acts as the “digital central nervous

system” of this system. Through widely deployed IoT sensors, drone remote sensing, and connections to government and market data platforms, it continuously collects multi-dimensional data on rural industries (e.g., crop growth, breeding environments), ecology (water, soil, air data), and, where measurable, governance and cultural indicators. It is important to clarify that while abstract concepts such as “culture” cannot be directly sensed by physical sensors, the platform operationalizes these dimensions through proxy indicators. For example, cultural activity participation rates are derived from registration data for village festivals and traditional craft workshops; governance efficiency is quantified through administrative data on policy implementation speed, public meeting attendance, and dispute resolution times; and social cohesion is approximated through survey-based metrics integrated at regular intervals rather than as real-time streams. These proxy measurements are updated periodically (e.g., weekly or monthly) rather than continuously, acknowledging the fundamental difference between physical and social phenomena. These data streams transform the virtual rural model from a static digital representation into a living entity that breathes and grows synchronously. For example, by integrating meteorological data and market price fluctuations, the model can predict the supply and demand situation for specialty agricultural products in the upcoming season; by monitoring homestay occupancy rates and tourist reviews, it can identify quality shortcomings in rural tourism services. These insights are translated into forward-looking demand signals for the knowledge and skill structures required of talent.

Within the “School-Village-Enterprise” collaboration, the digital twin platform plays the role of a common context creator and trust intermediary. Previously, schools designed courses based on outdated materials, enterprises made demands based on vague market intuition, and villages passively received talent—all three lacked a unified, objective basis for dialogue. Now, based on the same high-fidelity rural digital twin, university teachers can extract real cases for teaching, enterprises can use it as a testing ground for product and service solutions, and villages can visually demonstrate their development bottlenecks and talent demands. For instance, focusing on the e-commerce promotion of “One Village, One Product,” the platform can simulate traffic, conversion rates, and logistics pressure under different marketing strategies. Student teams can design and compete with solutions in the virtual environment, guided by enterprise mentors, with the winning scheme piloted in a real village. This process transforms discrete cooperation into synergistic projects with focused objectives, visualized processes, and measurable outcomes.

Digital twins also profoundly alter the modes of learning and competency development. They support the creation of high-immersion, low-risk virtual training environments. Trainees can repeatedly practice operating large agricultural machinery, dealing with sudden agricultural disasters, or managing a virtual cooperative in the digital twin environ-

ment. All operations are recorded to form a competency profile. This “simulation-verification-feedback” closed loop aligns with the core concept of the “C+R” (Cloud control + Real-field execution) training model of Hunan Automotive Engineering Vocational University, significantly expanding the spatiotemporal boundaries and content breadth of practical teaching[7]. More importantly, the platform establishes a “digital growth portfolio” for each learner, accompanying their career development and continuously recording their knowledge, skills, project experiences, and innovative achievements. This portfolio serves personalized learning recommendations and provides a comprehensive record of skill acquisition that can supplement—but not replace—formal credentialing systems. It is important to note that while this portfolio can demonstrate competency to potential employers or cooperative partners, its acceptance as a formal “credit credential” for financial loans by regulated banking institutions remains unvalidated and would require integration with existing credit assessment frameworks.

Furthermore, the model’s assumption that “cultivating one person” directly leads to “settling one case” and “empowering an entire area” requires critical examination. In practice, rural revitalization faces significant challenges including urban migration and brain drain, where trained talent may leave rural areas for urban opportunities. The platform does not itself solve these socio-economic barriers; rather, it provides technical infrastructure that must be complemented by policy interventions—such as improved rural housing, competitive compensation structures, and career advancement pathways—to achieve sustainable talent retention. The causal chain from individual training to regional empowerment is therefore mediated by these external factors, and the platform’s effectiveness should be evaluated within this broader context.

III. PLATFORM CORE ARCHITECTURE AND KEY TECHNOLOGY IMPLEMENTATION

A. OVERALL ARCHITECTURE DESIGN

Based on the aforementioned theoretical framework, the proposed “School-Village-Enterprise” collaborative talent cultivation digital twin platform adopts a loosely coupled, modular four-layer architecture design, as shown in Figure 1. This architecture aims to ensure the platform’s openness, scalability, and robustness.

The Data Perception and Acquisition Layer is the foundation of the platform. It consists of various intelligent sensing terminals deployed in the rural physical environment, including agricultural IoT nodes for monitoring soil moisture, nutrients, and pests/diseases, facility status sensors for collecting rural living environment data, and integrated air-space-ground perception data incorporating satellite remote sensing and drone aerial photography. For socio-economic and cultural dimensions, the platform integrates survey data, administrative records, and participatory sensing inputs (e.g., mobile app-based reports from villagers) that are aggregated and updated at daily, weekly, or monthly intervals

rather than as continuous real-time streams. In the field of agricultural geographic information, using technologies like Generative Adversarial Networks (GANs) to generate high-fidelity, highly usable surface imagery has become an effective cutting-edge solution for enhancing the quality of digital twin foundational data[8]. Video data is collected via 5G and edge computing nodes, while sensor data is transmitted using LoRaWAN low-power wide-area networks. Additionally, this layer accesses multi-source heterogeneous data such as county government data (e.g., population, economic statistics), e-commerce platform transaction data, and agro-enterprise production management data through standardized data interfaces. All data undergoes preliminary cleaning, fusion, and encryption at edge computing gateways before being uniformly transmitted to the cloud. Considering rural network conditions, this layer is designed to support breakpoint resume transmission and protocol adaptation to ensure data acquisition continuity.

The Model Construction and Simulation Layer is the technical core of the platform. This layer receives real-time data streams from the perception layer and drives the dynamic update of the rural digital twin. The construction of the digital twin is not merely simple 3D scene modeling but an organic integration of multi-dimensional, multi-scale model clusters. It includes at least: 1) Geometric Model: High-precision 3D reality-based models of rural areas constructed via oblique photography and LiDAR scanning, providing spatial reference for collaborative tasks. 2) Physical Model: Such as crop growth models, water and fertilizer movement models, small agricultural machinery dynamics models, etc., used to simulate natural laws and physical processes. 3) Behavioral Model: Simulating the behavioral logic and interaction rules of agents like villagers, operators, and tourists. 4) Rule Model: Encapsulating the logic of rural governance policies, market rules, and business processes. These models are interconnected via an ontology-based knowledge graph, forming a complex system simulation environment capable of supporting “what-if” analysis. For example, it can simulate the ripple effects on local traffic, environment, and employment after introducing a new rural tourism project.

The Service Application and Empowerment Layer encapsulates core functional modules for different users. For learners, the platform provides services such as personalized learning path planning, virtual simulation training, competency diagnosis, and certification. For university teachers, it offers services including a real case library, collaborative teaching and research tools, and teaching process analysis. For enterprises and rural managers, it provides services like talent demand release, collaborative project management, and decision-making simulation. All services are provided in the form of microservices and are managed and scheduled through a unified API gateway, supporting flexible combination and expansion based on actual needs. The Interaction Interface and Portal Layer is the window for user-platform interaction. Catering to different user roles

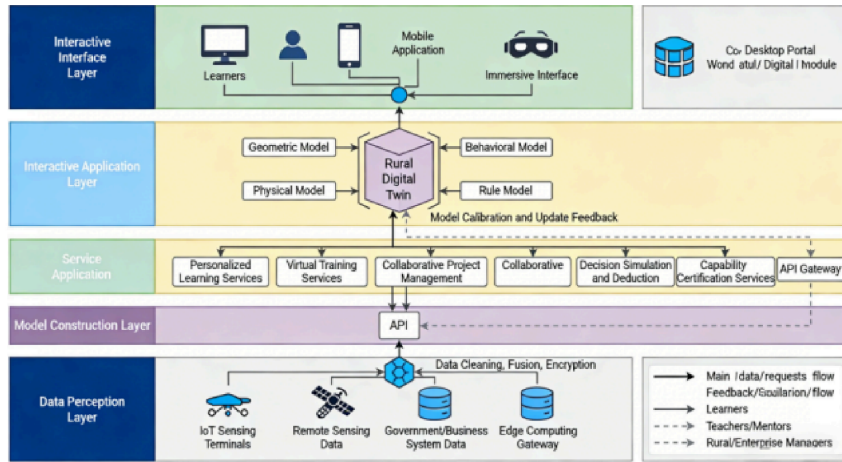


FIGURE 1. Overall Architecture of the Rural "School-Village-Enterprise" Collaborative Talent Cultivation Digital Twin Platform

and usage scenarios, the platform provides diverse access terminals and interaction methods. These include a comprehensive management portal for desktop use, lightweight applications for mobile devices, and VR/AR interfaces designed for immersive training. Interface design emphasizes context awareness and user experience, ensuring that even rural users unfamiliar with complex technology can access required services conveniently.

B. KEY TECHNOLOGY IMPLEMENTATION PATHS

Digital Twin Construction and Update. To achieve a high-fidelity and computable digital twin, we propose a dynamic modeling method based on multi-modal data fusion. Its core process includes: 1) Data Alignment and Spatiotemporal Reference Unification: Utilizing improved Iterative Closest Point algorithms and spatiotemporal indexing techniques to unify data from different sources and resolutions within the same spatiotemporal framework. 2) Multi-level Model Fusion: Adopting a "white-box + black-box" hybrid modeling strategy[9]. For physical processes with relatively clear mechanisms (e.g., heat and moisture transfer in greenhouses), "white-box" models based on physical equations are used, with parameters calibrated using optimization methods like genetic algorithms on measured data. For complex socio-economic behaviors, "black-box" models like machine learning are employed for data-driven modeling. 3) Incremental Learning and Dynamic Update: Designing an online learning mechanism where, when new data flows in, only the affected parameters of the model are fine-tuned instead of reconstructing the entire model, thereby ensuring real-time and efficient twin updates.

Personalized Learning Path Recommendation Algorithm. To overcome the "one-size-fits-all" cultivation drawback, the platform needs to intelligently plan growth paths for each learner. We design a recommendation algorithm that integrates Knowledge Graph and Reinforcement Learning (KG-RL-PR). First, based on the skill demands extracted from the rural digital twin and combined with disciplinary systems, a rural talent competency knowledge graph cover-

ing professional knowledge, practical skills, and comprehensive qualities is constructed. Nodes in the graph represent knowledge or skill points, and edges represent prerequisite or correlation relationships. Each learner's learning behaviors, training performance, project outcomes, etc., within the platform are mapped to a mastery state vector S for a subset of this graph.

$$S = (s_1, s_2, \dots, s_n), \quad s_i \in [0, 1]. \quad (1)$$

Here, s_i represents the mastery level of the i -th knowledge/skill node, and n is the total number of graph nodes. The algorithm models learning path planning as a sequential decision-making problem: given the current state s_t and a target state S_g (Jointly determined by personal career inclination and rural needs), the agent (recommendation system) needs to choose the next optimal learning activity a_t (e.g., taking a specific course, participating in a virtual training session).

Traditional cumulative reward formulas have convergence flaws. This study adopts the Q-learning temporal difference update rule:

$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha \left[r_t + \gamma \max_a Q(s_{t+1}, a) - Q(s_t, a_t) \right]. \quad (2)$$

Where $s_t \in S$ is the state at time t , $a_t \in A$ is the action, $r_t = r(s_t, a_t, s_{t+1})$ is the immediate reward, $\alpha = 0.1$ is the learning rate, $\gamma = 0.95$ is the discount factor (determined through ablation experiments, where $\gamma = 0.95$ yielded policy convergence and optimal stability within 50 steps), and $T \leq 50$ is the maximum number of steps per episode. This Q-learning update rule progressively converges to the optimal policy by minimizing temporal difference error.

Cross-Domain Collaboration and Resource Scheduling Mechanism. The platform needs to efficiently schedule resources such as faculty, projects, and equipment dispersed among schools, enterprises, and villages. Rather than introducing blockchain smart contracts for low-volume, high-

TABLE 1. Core Components and Functions of the Platform's Four-Layer Architecture

Architecture Layer	Core Components	Main Functions	Key Technology Examples
Interaction Interface Layer	Comprehensive Portal, Mobile Applications, VR/AR Terminals	Provides multi-modal, role-based human-computer interaction interfaces	Responsive Web Design, Unity3D, Lightweight AR SDK
Service Application Layer	Learning Services, Training Services, Collaboration Services, Management Services	Encapsulates business logic, provides various empowerment tools and functionalities	Microservices Architecture, Docker Containerization, Rule Engine
Model Construction Layer	Geometric Models, Physical Models, Behavioral Models, Rule Models	Integrates multi-dimensional, multi-scale models to drive digital twin simulation and deduction	System Modeling Language (SysML), AgroGeoInformatics, Multi-Agent Simulation
Data Perception Layer	Video: 5G and Edge Computing Nodes; Sensors: LoRaWAN + MQTT	Performs comprehensive, real-time acquisition of rural physical and social data	Video: 5G MEC; Sensors: LoRaWAN, MQTT Protocol, Edge Computing, Data Bus

trust institutional collaborations—which would add unnecessary technical complexity—we adopt a more pragmatic centralized management system. A relational database-backed scheduling module tracks resource availability (e.g., enterprise mentor consulting hours, school training software licenses, village practical project slots) and manages reservations through a simple priority queue and calendar-based allocation. This approach is more efficient for the typical scale of School-Village-Enterprise collaborations, which involve a manageable number of participating institutions (typically 5-20 per regional cluster) and low-frequency scheduling events (e.g., weekly mentor sessions). The system maintains an audit log of all transactions for transparency and dispute resolution, without the overhead of distributed consensus mechanisms. All participants can register their shareable resources (e.g., an enterprise mentor's 1-hour consulting time, a school's training software license, a real-world practical topic from a village) in a centralized directory. When a collaborative need arises on the platform (e.g., a student team needing enterprise mentor guidance for their rural e-commerce plan), the scheduling module can automatically match and execute resource usage agreements based on availability and priority rules. The entire process is recorded in a tamper-evident database log, and contributions are measured based on preset rules, providing a transparent and credible basis for subsequent benefit distribution or incentives. To ensure meaningful enterprise participation, the platform must address a fundamental question: Why would businesses invest time and resources? The incentive mechanism extends beyond symbolic "platform points" redeemable for university training resources. Concrete ROI (Return on Investment) drivers include: (1) direct recruitment pipelines, where enterprises gain early access to vetted talent who have demonstrated practical skills through platform projects, reducing hiring risks and onboarding costs; (2) research and development offsets, where student project teams generate innovative solutions to operational challenges that enterprises can adopt or adapt, effectively outsourcing exploratory R&D at low cost; (3) corporate social responsibility credits that can be reported to stakeholders and may qualify for tax benefits or government procurement preferences in some jurisdictions; and (4) operational efficiency gains through access to the

platform's digital twin for low-cost simulation and testing of new products or processes before field deployment. The platform incorporates a dashboard for enterprises to track these tangible benefits, with ROI calculators that estimate recruitment cost savings (e.g., reduced time-to-hire from 90 to 30 days) and innovation value captured from student projects.

IV. PLATFORM APPLICATION SCENARIO AND OPERATIONAL MODE: THE CASE OF "DIGITAL COMMERCE REVITALIZING AGRICULTURE"

To more concretely illustrate the platform's operation and value, this section depicts a typical application scenario using the currently urgent need for "Digital Commerce Revitalizing Agriculture" talent cultivation as an example[10]. *Scenario Initiation: Precise Demand Insight and Project Generation.* A citrus cooperative in a certain county updates its annual yield forecast, fruit quality inspection data, and past sales channel analysis on the digital twin platform. Combining external data such as nationwide citrus product sales trends and logistics cost fluctuations, the platform model, through simulation and deduction, discovers that if the cooperative continues using traditional wholesale channels, it might face price pressure; whereas, attempting to develop "short video + live streaming" direct sales offers higher market premium potential but carries risks like operational talent shortages and insufficient logistics/quality control experience. This insight is automatically transformed into a clear "Digital Commerce Revitalizing Agriculture" project requirement package and published in the platform's collaborative project hall. The requirement package not only describes the overall goal of helping the cooperative establish and operate direct sales channels but also generates a virtual "Citrus Cooperative Operation Sandbox" within the digital twin environment, containing the cooperative's 3D scene, historical data, simulated customer traffic, etc., for preliminary research and analysis by participants.

Collaborative Process: Cross-Role Virtual Teams and Progressive Empowerment. A teacher from the e-commerce major of a vocational and technical college in the province claims the project and designs it as a semester-long "project-based course." Ten students from the college form a team online. Simultaneously, based on project requirements and student competency profiles, the platform intelligently rec-

ommends an operations expert from an e-commerce enterprise and a technical consultant from a logistics company as enterprise mentors. After project initiation, the student team first conducts market research and analysis within the digital twin's "Cooperative Sandbox," using the platform's AI tools to generate competitor analysis reports and preliminary marketing strategies. Enterprise mentors provide regular online guidance and review the plans via the platform's remote collaboration tools. During the core live streaming skills training phase, students do not directly face real customers initially. Instead, they enter a "High-Fidelity Live Streaming Training Pod" constructed by the platform. This virtual pod 1:1 replicates the lighting and setup of a live streaming room and uses virtual digital human generation technology to simulate a virtual customer group with different identities and interests.

However, a critical limitation must be acknowledged: the unpredictability of real human consumers in live e-commerce—including non-standard questions, emotional reactions, trolls, and off-script interactions—constitutes the primary authentic challenge that trainees must ultimately master. Scripted AI simulations, by their nature, cannot fully replicate this volatility. To address this, the platform's training pod is designed with multiple progressive stages. Stage 1 (Foundation) uses scripted AI customers with predictable response patterns to teach basic live streaming workflows and product presentation skills. Stage 2 (Variable) introduces stochastic behavioral models where AI customer responses are sampled from probability distributions derived from real e-commerce session data, including a 15-20% rate of unexpected or challenging interactions (e.g., refund requests, product comparisons, technical complaints). Stage 3 (Adversarial) incorporates an adversarial agent trained via reinforcement learning to actively probe weaknesses in the trainee's presentation, simulating difficult but realistic scenarios. Stage 4 (Real Shadowing) pairs trainees with real live streaming sessions where they observe and then co-host with experienced streamers, receiving real-time feedback. This staged approach mitigates the risk of "false mastery," where competence in a simplified simulation fails to transfer to real-world complexity. Performance metrics across these stages are tracked, and trainees must achieve threshold scores in Stage 3 before progressing to real customer interactions.

Solution Verification and Landing Iteration. Once the team develops a relatively mature live streaming and operations plan, it can undergo "stress testing" in the digital twin environment: the platform simulates massive traffic surges during events like "Double Eleven" or logistics delays caused by weather, testing the team's emergency response capabilities. After multiple rounds of virtual deduction and optimization, the final solution is piloted on a small scale in the cooperative's real scenario. Sales data, customer feedback, logistics information, etc., from the pilot are fed back into the digital twin platform in real-time to calibrate the models and serve as input for the next round of talent

cultivation or project optimization.

Value Loop and Sustained Incentives. Throughout this process, students' learning outcomes (project participation, plan quality, training performance) are recorded in their digital growth portfolios and may be exchanged for credits or skill certifications within the educational institution's existing credit framework, subject to formal articulation agreements. The portfolio serves as a supplementary credential that students can present to employers or cooperative partners, but it is not positioned as a substitute for regulated financial credit instruments. The contributions of enterprise mentors are recorded and may earn preferential recruitment access to platform-trained talent, R&D collaboration opportunities with the university, and recognition in corporate social responsibility reporting, which may provide tax or procurement advantages in some jurisdictions. The cooperative gains low-cost, low-risk innovative solutions and potential talent reserves. The platform accumulates this complete "Digital Commerce Revitalizing Agriculture" project case, including its process data, success factors, and challenges, transforming it into a reusable digital asset for other regions to learn from and replicate, thereby realizing the value amplification effect of "cultivating one person, serving one village, settling one case, empowering an entire area"[11], with the explicit understanding that this value chain depends on complementary retention policies and that the platform alone cannot guarantee talent stays in rural areas.

V. CHALLENGES, COUNTERMEASURES, AND FUTURE PROSPECTS

While the digital twin-based collaborative talent cultivation platform holds considerable promise, its development and promotion encounter a series of practical challenges that necessitate focused attention in future research and practice.

The foremost challenge pertains to data barriers and privacy security. Rural data encompasses diverse aspects such as farmer household production operations and rural governance. The boundaries defining its collection, sharing, and usage are often ambiguous, accompanied by high risks of sensitive information leakage. The proposed "Rural Data Cooperative" model—while conceptually promising—faces significant legal and bureaucratic friction in practice. Accessing real-time data streams from government and market platforms requires navigating multiple regulatory frameworks (e.g., personal information protection laws, agricultural data sharing regulations, commercial confidentiality agreements). Based on similar pilot projects in Zhejiang Province, the timeline for establishing comprehensive data sharing agreements across diverse databases typically ranges from 6 to 18 months, not including technical integration. Therefore, a phased implementation approach is recommended: Phase 1 (months 1-6) focuses on data from willing pilot villages and open government datasets; Phase 2 (months 6-12) establishes formal MOUs with county-level agricultural bureaus and select enterprises; Phase 3 (months 12-24) expands to broader regional data integration as legal

frameworks mature. The Deqing County model, where the County Big Data Bureau acts as a trustee authorized by the Village Representative Assembly, serves as a reference point, but scaling this model requires substantial institutional capacity building. From a technological standpoint, enhancing the application of privacy-preserving computation techniques like federated learning and homomorphic encryption is crucial to ensure data remains “usable but invisible.” Policy-wise, there is a pressing need to accelerate the formulation of rural data classification, grading standards, and usage norms[12].

The second challenge concerns model credibility and domain adaptability. Existing mechanistic models in agriculture and rural sectors inherently contain uncertainties, while machine learning models require substantial volumes of high-quality training data—a requirement difficult to meet across the heterogeneous contexts of rural areas. The solution lies in advancing domain-enhanced hybrid intelligent modeling. This involves, on one hand, deeply integrating expert knowledge from fields like agriculture, ecology, and sociology to impose strong constraints on models. On the other hand, leveraging technologies such as transfer learning and few-shot learning can enable models trained in one region to adapt swiftly to other villages with similar characteristics, thereby reducing model development costs. The platform itself should incorporate mechanisms for continuous model performance monitoring and reporting, clearly communicating the prediction confidence intervals and applicability boundaries of its models to users.

The third challenge is the digital divide and user adoption. The platform’s ultimate success hinges on whether the broad base of rural teachers, students, enterprises, and villagers can genuinely use it and use it effectively. It is imperative to avoid prioritizing technological sophistication over the real user experience. This necessitates that platform design adheres to “user-centered” and “inclusive design” principles, offering simple, intuitive interfaces and supporting farmer-friendly functionalities like voice interaction and dialect recognition. Concurrently, systematic digital literacy enhancement programs must be implemented to cultivate a cohort of “rural digital mentors” who possess an understanding of both rural contexts and technology, serving as vital bridges connecting the platform with end-users.

Looking forward, the evolution of this platform will progress in tandem with advancements in next-generation information technologies. As AI large models mature, the platform is anticipated to develop deeper natural language interaction and content generation capabilities, potentially evolving into a “personal intelligent growth assistant” for each rural learner. The increasing prevalence of extended reality (XR) technologies will render virtual training environments more immersive and realistic. Furthermore, the deeper integration of blockchain technology will furnish a robust foundation for achieving precise contribution measurement and equitable value distribution across regions and institutions, thereby fostering the development of a more

prosperous, autonomous, and sustainable digital ecosystem for rural talent.

VI. CONCLUSION

Rural revitalization hinges on human capital, yet faces profound challenges in talent cultivation within tech-intensive production and advanced material research. Bridging this gap requires a systematic approach to developing a workforce capable of mastering automated engineering to drive sustainable regional industrial growth. To address systemic issues of mismatched supply-demand dynamics, fragmented resources, and ineffective collaboration in current rural education systems, this study innovatively proposes a digital twin technology-based collaborative education platform integrating universities, villages, and enterprises. Research demonstrates that constructing a real-time mirrored, physically-virtually interactive, and computationally analyzable rural digital twin establishes a precise “digital bridge” connecting educational resources with rural development needs. The platform explicitly distinguishes between directly measurable physical variables (e.g., soil moisture, infrastructure status) and socio-economic proxy indicators (e.g., cultural participation rates, governance efficiency metrics) that are updated at appropriate intervals rather than as continuous real-time streams. The platform’s four-layer architecture and technical pathways, particularly its multimodal fusion digital twin construction methodology and knowledge graph-reinforcement learning integrated personalized recommendation algorithm, provide a viable technical framework for this vision. The platform’s core value lies in its systemic integration and empowerment capabilities. Beyond a mere pedagogical tool, it functions as a digital infrastructure consolidating multi-stakeholder resources, orchestrating collaborative workflows, and supporting lifelong learning. A pragmatic centralized resource scheduling system is adopted over blockchain-based solutions, as the latter would introduce unnecessary technical complexity for low-volume, high-trust institutional collaborations. Application scenarios exemplified by “Digital Empowerment for Rural Revitalization” (leveraging digital technologies to invigorate agriculture) demonstrate seamless integration of theoretical learning, virtual simulation, and real-world practice. The live streaming training pod implements progressive stages including stochastic and adversarial AI simulations to mitigate the risk of “false mastery” before trainees face real customers. This approach reduces training costs and risks while significantly enhancing the targeted effectiveness of talent development. Ultimately, it generates reusable digital assets, enabling sustained value circulation and amplification.

However, the study critically acknowledges several limitations and boundary conditions. The causal chain from individual training to regional empowerment is mediated by external socio-economic factors, particularly urban migration and brain drain, which the platform does not directly address. Meaningful enterprise participation requires clear ROI

drivers beyond symbolic incentives; the platform therefore incorporates direct recruitment pipelines, R&D offsets, and CSR benefits as complementary mechanisms. The “digital growth portfolio” serves as a supplementary credential but is not positioned as a substitute for regulated financial credit instruments. Finally, full implementation faces challenges including data security (with phased rollout timelines of 12-24 months for comprehensive data sharing agreements), model trustworthiness, and digital inclusiveness, requiring coordinated efforts in technology, institutional design, and humanistic considerations. Future research should focus on domain-specific model refinement, human-machine collaborative education paradigms, and platform sustainability mechanisms. As digital technologies converge with rural development, this digital twin-driven collaborative education model will provide essential intelligence for digitizing production workflows and fiber engineering education, thereby resolving talent revitalization challenges. By simulating smart manufacturing environments, this framework solidifies the intellectual foundation for rural revitalization through a high-tech industrial workforce.

AUTHOR CONTRIBUTIONS

Lijuan Long designed, collected and analyzed the data, and drafted the manuscript. Lijuan Long conducted the study, critically revised the manuscript for important intellectual content, and gave final approval of the version to be published. Lijuan Long participated fully in the work, take public responsibility for appropriate portions of the content, and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

CONFLICTS OF INTEREST

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