

Collaborative Education Mechanism and Cross-Regional Implementation Path for Digital-Intelligent Rail Transit Talents in the Guangdong-Hong Kong-Macao Greater Bay Area

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Abstract

Under the unique institutional background of “One Country, Two Systems”, with three separate legal jurisdictions in the Guangdong-Hong Kong-Macao Greater Bay Area (GBA), the collaborative cultivation of digital-intelligent rail transit operation talents is constrained by prominent cross-regional institutional barriers, insufficient motivation for enterprise participation, imperfect multi-stakeholder operation mechanisms, and the lack of unified regional talent training standards. Based on stakeholder theory, institutional design theory, and collaborative governance theory, this study constructs a systematic “government-university-enterprise-research” four-in-one collaborative education mechanism with “benefit sharing, risk sharing, responsibility co-bearing” as its core. The mechanism includes a multi-dimensional dynamic motivation mechanism, a standardized and normalized operation mechanism, a multi-level guarantee mechanism, and a whole-process monitoring and evaluation mechanism. Meanwhile, this study designs a complete set of operable cross-regional implementation paths, including curriculum interconnection and credit mutual recognition, teacher sharing and team co-construction, practical training platform co-construction and resource sharing, vocational qualification mutual recognition and standard connection, as well as cross-regional talent mobility and employment docking. Through empirical research based on 7 vocational colleges and 18 key rail transit enterprises in the GBA, this paper verifies the practical effects of the mechanism and paths. The results show that after the implementation of the mechanism, enterprise participation enthusiasm increases by 58.3%, the per capita training cost of enter-

prises decreases by 32.7%, the proportion of cross-regional cooperative colleges rises from 14.3% to 71.4%, and 12 professional skill certificates have achieved mutual recognition in the GBA. The employment rate of graduates increases from 86.2% to 97.8%, and enterprise satisfaction reaches 94.3%. This study breaks through institutional barriers, stimulates the endogenous vitality of collaborative education, optimizes the allocation of regional educational resources, and provides an operable, reproducible, and extendable model for the high-quality collaborative cultivation of digital-intelligent rail transit talents in the GBA.

Keywords

Collaborative Education, Digital-Intelligent Talents, Rail Transit, School-Enterprise Integration, Cross-Regional Cooperation, Talent Training, Guangdong-Hong Kong-Macao Greater Bay Area

1. Introduction

The Guangdong-Hong Kong-Macao Greater Bay Area is one of the most dynamic and promising city clusters in the world, undertaking important national strategic missions such as scientific and technological innovation, industrial upgrading, infrastructure connectivity, and regional integrated development. As the core backbone supporting the “one-hour living circle” of the GBA, rail transit has entered a stage of large-scale construction, networked operation, and digital-intelligent transformation. According to official data released by the Guangdong Provincial Department of Transportation, by the end of 2024, the total operating mileage of rail transit in the GBA had exceeded 2700 kilometers, covering high-speed railways, intercity railways, urban subways, automated people movers, and other multi-level network systems. The Guangdong-Hong Kong-Macao Greater Bay Area Intercity Railway Construction Plan clearly states that the scale of the regional rail network will reach 5700 kilometers by 2035, forming a “axis-supported, radial, and highly connected” modern rail transit system [1].

Against this background, new technologies such as artificial intelligence, big data analytics, the Internet of Things, cloud computing, and digital twins have been deeply integrated into all links of rail transit operation and management, including fully automatic operation (FAO), intelligent scheduling, predictive maintenance, digital operation, intelligent security, and passenger flow monitoring. These technological changes have completely reconstructed the demand structure of rail transit talents. Traditional operation and maintenance talents can no longer meet the needs of industrial development. Enterprises urgently need a large number of compound digital-intelligent talents who master both professional rail transit operation knowledge and digital technology application capabilities [2].

However, under the special institutional context of “One Country, Two Sys-

tems”, with three separate legal jurisdictions, the talent training system of rail transit in the GBA is facing severe challenges and practical dilemmas. First, cross-regional institutional barriers are significant. There are substantial differences in education systems, vocational qualification certification systems, industry standards, and management norms among Guangdong, Hong Kong, and Macao, which hinder the free flow of educational resources, the interconnection of courses, the mutual recognition of credits, and the mobility of talents. Second, the depth and effectiveness of school-enterprise cooperation are insufficient. Most cooperation remains at a shallow level such as simple internship arrangement, equipment donation, and part-time employment, lacking in-depth integration in curriculum development, teacher co-construction, practical training base co-construction, and technical research and development. The long-standing problem of “schools being enthusiastic while enterprises being cold” has not been fundamentally solved. Third, the collaborative education mechanism is incomplete. There is a lack of systematic motivation mechanisms, reasonable benefit distribution mechanisms, standardized operation processes, and perfect guarantee systems, resulting in low cooperation efficiency and poor sustainability. Fourth, the unified regional talent training standard has not yet been formed, leading to inconsistent training objectives, inconsistent curriculum systems, and inconsistent evaluation criteria among different regions and institutions, which reduces the regional adaptability and mobility of talents [3] [4].

To address the above problems, this study relies on the provincial higher education research project Research on Collaborative Training Mechanism Innovation and Implementation Path of Digital-Intelligent Rail Transit Operation Talents in the Guangdong-Hong Kong-Macao Greater Bay Area, takes the demand of high-quality development of rail transit in the GBA as the orientation, and focuses on the core issue of multi-stakeholder collaborative education. This study constructs a systematic and complete collaborative education mechanism and designs a set of cross-regional implementation paths with strong operability. The research adopts a mixed research method of investigation research, theoretical modeling, mechanism design, empirical analysis, and case verification. The research results are expected to break through institutional barriers, stimulate the vitality of collaborative education, optimize the allocation of educational resources, improve the quality of talent training, and provide important theoretical support and practical solutions for promoting the integrated development of education chain, talent chain, industrial chain, and innovation chain in the GBA [5] [6].

2. Literature Review and Theoretical Basis

2.1. Research Status of Collaborative Education for Rail Transit Talents

In recent years, with the rapid development of rail transit and the continuous promotion of vocational education reform, domestic and foreign scholars have car-

ried out extensive and in-depth research around talent training models, school-enterprise cooperation, and regional collaborative education.

Foreign vocational education has formed a relatively mature system of collaborative education. Germany's dual-system vocational education takes enterprises and schools as dual subjects, and enterprises participate deeply in the whole process of talent training, including curriculum formulation, teaching implementation, practical training, and assessment and evaluation, which ensures that skill training is highly consistent with post demand. Japan's rail transit industry-university-research alliance realizes resource sharing, standard co-construction, and talent co-cultivation among multiple enterprises, universities, and research institutions, and has established a unified regional vocational ability standard and certification system. Singapore's "teaching factory" model introduces real enterprise working environments and projects into campus teaching, realizing the organic integration of theoretical teaching and practical training. Although these models have achieved remarkable results, they are all formed under a single institutional system and cannot be directly copied to the GBA with the special background of "One Country, Two Systems", with three separate legal jurisdictions [7].

Domestic research mainly focuses on three aspects: talent demand analysis under digital-intelligent transformation, innovation of talent training models, and regional collaborative training. Some scholars have analyzed the changes in talent demand structure caused by digital-intelligent transformation of rail transit, and constructed competency models for intelligent operation and maintenance posts. Some studies have taken vocational colleges as examples to explore the "post-course-competition-certificate" integration training model and virtual simulation teaching reform. Some scholars have studied the collaborative training of rail transit talents in the Yangtze River Delta, Chengdu-Chongqing Economic Circle, and other regions, and put forward paths such as curriculum sharing, teacher mutual employment, and base co-construction [8].

However, the existing research still has obvious deficiencies. First, few studies involve cross-regional collaborative education under the background of "One Country, Two Systems", with three separate legal jurisdictions, and the response to institutional differences is insufficient. Second, the systematic design of collaborative education mechanism is lacking, especially the solutions to enterprise motivation, benefit distribution, and risk sharing are not perfect. Third, there is a lack of large-sample empirical verification and long-term effect tracking, which affects the reliability and promotion value of the research results. This study fills the above gaps and enriches the theoretical and practical system of cross-regional collaborative education of rail transit talents [9].

2.2. Theoretical Basis

This study is supported by three core theories: stakeholder theory, institutional design theory, and collaborative governance theory. Each theoretical lens is closely linked to the design of the four-in-one collaborative education mechanism, and

the theoretical connotation is embedded in the core logic of different mechanism components to form a theoretical support system with clear correspondence and strong applicability.

Stakeholder theory holds that talent training involves multiple stakeholders such as government, universities, enterprises, research institutions, students, and society, and each stakeholder has its own interest demands and behavioral logic. Only by clarifying the rights, responsibilities, and interests of all parties, balancing the interests of all parties, and forming a pattern of benefit sharing, risk sharing, and responsibility co-bearing can stable and sustainable cooperative relations be established. This theory provides a basic analytical framework for the construction of the multi-dimensional dynamic motivation mechanism in this study, and is the core theoretical basis for designing the “three compensations and three sharings” mechanism to balance the interest demands of government, universities, enterprises and research institutions.

Institutional design theory emphasizes that reasonable and perfect institutional arrangements can reduce transaction costs, resolve conflicts of interest, and standardize behavioral subjects. Aiming at the cross-regional institutional differences and cooperation obstacles in the GBA, this study designs a set of standardized, flexible, and compatible institutional systems to realize the connection of educational standards, certification systems, training modes, and evaluation mechanisms among different regions. This theory is the theoretical foundation for the construction of the standardized and normalized operation mechanism and multi-level guarantee mechanism, guiding the formulation of unified talent training standards, standardized cooperation processes, and perfect institutional and organizational guarantee systems.

Collaborative governance theory advocates that multiple subjects form a cooperative network through communication, consultation, resource integration, and joint participation to solve public problems or achieve common goals. Applied to talent training, it means that government, universities, enterprises, and research institutions jointly participate in talent training, realize resource sharing, complementary advantages, and coordinated education, and jointly improve the quality of talent training. This theory provides a theoretical basis for the construction of the whole-process monitoring and evaluation mechanism, and supports the establishment of a multi-subject participation, whole-process tracking and dynamic optimization evaluation system covering government supervision, school-enterprise joint evaluation, and research institution technical assessment.

3. Research Methodology

This study adopts a mixed research method combining qualitative and quantitative approaches to ensure the scientificity, reliability, and practicability of the research results.

First, literature analysis method. This study systematically sorts out domestic and foreign literature related to collaborative education, rail transit digital-intelli-

gent transformation, talent training, cross-regional cooperation, and vocational education reform, collects and organizes relevant national and regional policy documents, industry development plans, enterprise annual reports, and typical case materials, clarifies the research status, theoretical basis, and practical experience, and lays a foundation for theoretical modeling and mechanism design.

Second, investigation and research method. From April 2024 to January 2025, this study conducted a large-scale and full-coverage special investigation on collaborative education of rail transit talents in the GBA. Sampling procedure and selection criteria: The 7 vocational colleges were selected by stratified random sampling according to the regional distribution (Guangdong Pearl River Delta core area, edge area) and professional setting strength (provincial key rail transit majors, general majors) of GBA vocational colleges, covering 5 municipal vocational colleges in Guangzhou, Shenzhen and Zhuhai, and 2 provincial vocational colleges in Guangdong; the 18 key rail transit operation enterprises were purposively sampled based on the enterprise scale, business type (urban rail transit, intercity railway, high-speed railway) and regional layout (Guangdong, Hong Kong), including Guangzhou Metro, Shenzhen Metro, Guangzhou Railway Group, MTR Corporation, and Guangdong Intercity Railway and other leading enterprises and backbone enterprises in the industry. Respondent distribution and questionnaire response rate: A total of 220 questionnaires were distributed to professional directors, teachers, enterprise managers, technical backbones, and human resource directors of the above institutions, and 186 valid questionnaires were recovered with an effective response rate of 84.5%. Among the respondents, there are 62 vocational college teachers and professional directors (33.3%), 98 enterprise managers, technical backbones and human resource directors (52.7%), and 26 industry research personnel (14.0%). Interview arrangement: 42 in-depth semi-structured interviews were conducted with the above respondents, including 15 college management personnel and professional leaders, 20 enterprise human resource directors and technical experts, and 7 industry policy researchers and research institution scholars. Questionnaire and interview instruments: The questionnaire is divided into 5 dimensions: current situation of school-enterprise cooperation, cross-regional education barriers, stakeholder interest demands, policy support expectations, and mechanism construction suggestions, with a total of 38 questions (including 29 closed questions and 9 open questions); the interview outline is designed around 6 core themes: practical difficulties of collaborative education, cost-benefit of enterprise participation, demand for unified talent standards, cross-regional resource sharing, guarantee conditions for cooperation, and optimization suggestions for mechanisms. The questionnaire has passed the reliability and validity test: the Cronbach's α coefficient of the overall scale is 0.892, and the Cronbach's α coefficient of each dimension is greater than 0.82, indicating good internal consistency; the KMO value is 0.856, and the Bartlett spherical test is significant ($p < 0.001$), indicating good structural validity. The interview outline was revised and improved after expert demonstration by 3 vocational education re-

searchers and 2 rail transit industry experts. This research has obtained the institutional ethical approval of the Academic Ethics Committee of Guangzhou Railway Polytechnic (Approval No.: GTXY-2024-012), and all respondents have signed informed consent forms before the investigation and interview. The investigation data is true and effective, providing a solid data support for the research.

Third, theoretical modeling and mechanism design method. Based on stakeholder theory, institutional design theory, and collaborative governance theory, combined with the actual investigation results, this study constructs a theoretical model of collaborative education of digital-intelligent rail transit talents in the GBA, and designs a systematic and complete collaborative education mechanism, including motivation mechanism, operation mechanism, guarantee mechanism, and monitoring and evaluation mechanism.

Fourth, empirical analysis and effect verification method. Pilot evaluation design: This study takes the pilot implementation of the mechanism in the 7 selected vocational colleges and 18 key enterprises as the research carrier, and adopts a one-group pre-test-post-test design for before-and-after comparison. The same 7 colleges and 18 enterprises were tracked for the whole process, with the baseline period from January 2024 to June 2024 (6 months, pre-implementation data collection) and the follow-up period from July 2024 to December 2025 (18 months, pilot implementation of the mechanism and post-implementation data collection). Definition and measurement of core outcome indicators:

1) Enterprise participation enthusiasm: Measured by the proportion of enterprises that take the initiative to participate in collaborative education links (curriculum co-construction, teacher co-construction, practical training base co-construction, etc.), calculated as $(\text{number of enterprises with active participation} / \text{total number of surveyed enterprises}) \times 100\%$;

2) Curriculum co-construction ratio: Calculated as $(\text{number of courses co-constructed by schools and enterprises} / \text{total number of core professional courses of rail transit}) \times 100\%$;

3) Teacher sharing and mutual employment ratio: Calculated as $(\text{number of teachers shared/mutually employed between schools and enterprises} / \text{total number of professional teachers in rail transit majors}) \times 100\%$;

4) Enterprise satisfaction with graduates: Measured by a 5-point Likert scale (1 = very dissatisfied, 5 = very satisfied) from the dimensions of professional competence, digital application ability, post adaptability and comprehensive quality, and the satisfaction rate is calculated as $(\text{number of enterprises with a score of 4 and above} / \text{total number of surveyed enterprises}) \times 100\%$;

5) Other indicators: Per capita training cost of enterprises is the average annual training investment per trainee calculated by enterprise human resource departments; the proportion of cross-regional cooperative colleges is $(\text{number of colleges with cross-regional education cooperation} / \text{total number of surveyed colleges}) \times 100\%$; the practical training base co-construction ratio is $(\text{number of practical training bases co-constructed by schools and enterprises} / \text{total number of$

practical training bases for rail transit majors) $\times 100\%$.

This study collects and compares the key indicators before and after the implementation of the mechanism, and uses SPSS 26.0 software for statistical analysis, including paired sample t-test (to verify the significant difference of indicators before and after implementation) and descriptive statistical analysis (to calculate the improvement rate/change of indicators), so as to verify the effectiveness and sustainability of the mechanism.

Fifth, stability test method. The coefficient of variation method is used to test the stability of the mechanism operation, which is used to evaluate the reliability and stability of the mechanism by measuring the discrete degree of each key indicator during the pilot implementation period.

4. Current Situation and Obstacles of Collaborative Education

4.1. Current Situation of Collaborative Education

Based on the investigation data of 7 vocational colleges and 18 rail transit enterprises in the GBA, this study conducts a statistical analysis of the current situation of collaborative education, and the results are shown in **Table 1**.

Table 1. Current situation of rail transit talent collaborative education in GBA.

Survey Indicators	Proportion of Positive Feedback	Main Constraints
In-depth school-enterprise cooperation	28.6%	Unbalanced cost-benefit, difficult coordination
Enterprises with high participation willingness	33.3%	High training cost, unclear intellectual property rights
Cross-regional cooperative colleges	14.3%	Different education systems, non-recognition of credits
Unified talent training standards	0%	Different industry standards, certification barriers
Stable long-term cooperation mechanism	21.4%	Lack of policy support and funding guarantee

It can be seen from the table that the current collaborative education of rail transit talents in the GBA is generally at a low level of development. The proportion of in-depth school-enterprise cooperation is less than 30%, the willingness of enterprises to participate is low, cross-regional cooperation is extremely scarce, and there is no unified regional talent training standard. The cooperation in curriculum co-construction, teacher sharing, and practical training base co-construction is also very limited, which seriously restricts the improvement of talent training quality.

4.2. Core Obstacles Restricting Collaborative Education

Through in-depth investigation, data analysis, and expert demonstration, this study summarizes four core obstacles restricting the collaborative education of digital-intelligent rail transit talents in the GBA.

First, cross-regional institutional barriers. Affected by the “One Country, Two

Systems”, with three separate legal jurisdictions, background, there are great differences in education systems, vocational qualification certification systems, industry standards, and management norms among Guangdong, Hong Kong, and Macao. These differences lead to difficulties in curriculum docking, credit transfer, qualification mutual recognition, and talent mobility among regions, and increase the transaction cost and coordination difficulty of cross-regional cooperation.

Second, lack of endogenous motivation for enterprise participation. Enterprises need to invest a lot of manpower, material resources, and financial resources in participating in talent training, including providing practical training positions, arranging technical backbones, purchasing training equipment, and undertaking training management. However, the direct economic benefits obtained by enterprises are not obvious, and there are risks such as talent loss and intellectual property disputes. As a result, enterprises lack endogenous motivation and initiative to participate in talent training.

Third, imperfect operation mechanism of collaborative education. There is no standardized cooperation process, clear responsibility division, reasonable benefit distribution plan, and perfect performance evaluation system in collaborative education. The cooperation between subjects mostly relies on personal relationships and temporary agreements, lacking institutionalization and standardization, resulting in low cooperation efficiency, poor stability, and difficult sustainability.

Fourth, insufficient multi-dimensional guarantee conditions. The support of special policies, special funds, and joint management organizations for collaborative education is lacking. The government’s guidance and support are insufficient, the school’s resource investment is limited, the enterprise’s willingness to share resources is not high, and the research institutions’ participation is insufficient. The incomplete guarantee system makes it difficult to carry out long-term and in-depth cooperative activities.

5. Construction of Four-in-One Collaborative Education Mechanism

5.1. Overall Framework

Based on stakeholder theory, institutional design theory, and collaborative governance theory, combined with the actual demand of digital-intelligent rail transit talents in the GBA, this study constructs a “government-university-enterprise-research” four-in-one collaborative education mechanism. The overall framework of the mechanism is shown as follows.

The government plays a leading and supporting role, responsible for policy formulation, fund support, supervision and management, and standard guidance. Universities are the main body of talent training, responsible for theoretical teaching, curriculum development, student management, and quality evaluation. Enterprises are the practical application side and demand side, responsible for providing post demand, practical training resources, technical guidance, and em-

ployment channels. Research institutions are the technical support side, responsible for technical research, standard development, model innovation, and effect evaluation.

The four subjects form a closed-loop collaborative education system of “policy guidance + talent training + practical practice + technical support” with clear division of labor, resource sharing, complementary advantages, and coordinated education, realizing the deep integration of education chain, talent chain, industrial chain, and innovation chain.

5.2. Motivation Mechanism: Three Compensations and Three Sharings

To solve the problem of insufficient motivation for enterprise participation, this study designs a “three compensations and three sharings” dynamic motivation mechanism.

Three compensations:

- Policy compensation: Provide tax incentives, project preferences, and honor incentives for enterprises participating in collaborative education.
- Economic compensation: Give special training subsidies, equipment subsidies, and management subsidies to reduce the cost of enterprise participation.
- Honor compensation: Include enterprise participation in talent training into the enterprise credit evaluation, brand evaluation, and industry rating system to enhance the social influence and brand value of enterprises.

Three sharings:

- Talent sharing: Enterprises give priority to hiring graduates trained by the collaborative education mechanism to realize the direct transformation of talent training results.
- Technology sharing: Schools and enterprises jointly carry out technical research and development, project transformation, and achievement application to realize the complementary advantages of technical resources.
- Achievement sharing: Jointly apply for patents, software copyrights, teaching achievements, and scientific research achievements, and distribute benefits according to the contribution ratio.

The benefit distribution model is constructed as follows:

$$B_{total} = B_{gov} + B_{uni} + B_{ent} + B_{res} \quad (1)$$

Where B_{total} represents the total benefit of collaborative education, and B_{gov} , B_{uni} , B_{ent} , and B_{res} represent the benefits obtained by the government, universities, enterprises, and research institutions respectively, matching their input.

5.3. Standardized Operation Mechanism: Dual Subject and Three Commons

To improve the efficiency and standardization of collaborative education, this study designs a “dual subject and three commons” standardized operation mechanism.

Dual subject: Schools and enterprises jointly serve as the main body of talent training, and jointly participate in the whole process of talent training, including training objectives formulation, curriculum system design, teaching team construction, practical training implementation, and quality evaluation.

Three commons:

- Jointly formulate talent training programs. Based on the post demand of digital-intelligent rail transit, schools and enterprises jointly determine training objectives, competency standards, curriculum modules, and teaching contents.
- Jointly build practical training bases. Integrate school and enterprise resources to build on-campus practical training centers and off-campus practical training bases, realizing the integration of practical training resources.
- Jointly implement teaching quality evaluation. Establish a multi-dimensional teaching quality evaluation system involving schools, enterprises, students, and industry experts to realize the whole-process monitoring and feedback of teaching quality.

5.4. Multi-Level Guarantee Mechanism

To ensure the long-term and stable operation of the collaborative education mechanism, this study constructs a multi-level guarantee mechanism including organizational guarantee, institutional guarantee, and funding guarantee.

1) Organizational guarantee: Establish a cross-regional and cross-subject collaborative education management committee, which is composed of government departments, colleges and universities, rail transit enterprises, and research institutions. The committee is responsible for overall planning, coordination and decision-making, problem solving, and supervision and evaluation.

2) Institutional guarantee: Formulate a series of standardized management systems, including collaborative education management measures, school-enterprise cooperation agreement templates, cross-regional credit mutual recognition management methods, vocational qualification mutual recognition implementation rules, benefit distribution management methods, and quality evaluation standards.

3) Funding guarantee: Establish a multi-channel funding security model of “government special subsidies + school special investment + enterprise supporting funding + social fund support” to provide stable financial support for curriculum development, practical training base construction, teacher training, and teaching operation.

5.5. Whole-Process Monitoring and Evaluation Mechanism

To realize the dynamic optimization of the collaborative education mechanism, this study designs a whole-process monitoring and evaluation mechanism. Establish a monitoring index system including cooperation operation, resource investment, teaching process, talent training quality, and employment effect. Regularly collect data, conduct statistical analysis, evaluate the operation effect of the mech-

anism, and form feedback and optimization suggestions to realize the closed-loop management of “operation-monitoring-evaluation-optimization”.

6. Cross-Regional Implementation Path of Collaborative Education

6.1. Curriculum Interconnection and Credit Mutual Recognition

Formulate a set of unified general professional curriculum standards for digital-intelligent rail transit talents in the GBA, clarify the core curriculum contents, teaching requirements, and competency standards. Establish a cross-regional credit transfer and mutual recognition system to realize the interconnection and mutual recognition of courses and credits among different regions and colleges. Develop bilingual teaching resources and digital course resources suitable for Hong Kong and Macao to promote the sharing of high-quality curriculum resources.

6.2. Teacher Sharing and Team Co-Construction

Build a GBA rail transit teacher resource pool integrating school teachers, enterprise technical experts, and industry researchers. Implement the “Hundred Technicians on the Platform” plan to encourage enterprise technical backbones to hold part-time positions in colleges and undertake teaching tasks. Establish a cross-regional teacher training and exchange mechanism, regularly carry out teaching observation, lesson preparation, and professional ability training, and improve the digital-intelligent teaching ability and cross-regional adaptability of teachers.

6.3. Practical Training Platform Co-Construction

Build a “one center, multiple bases” cross-regional practical training platform network. Build a digital-intelligent rail transit virtual simulation training center in Guangzhou to develop virtual training projects such as automatic operation, intelligent scheduling, and fault maintenance. Build physical practical training bases in Shenzhen Qianhai, Zhuhai Hengqin, and Hong Kong to provide real post practical training opportunities. Realize the cross-regional opening and sharing of practical training platforms and improve the utilization efficiency of resources.

6.4. Vocational Qualification Mutual Recognition

Organize industry experts from Guangdong, Hong Kong, and Macao to jointly formulate unified vocational ability standards for typical digital-intelligent posts of rail transit. Establish a “one test, multiple certificates” evaluation system. Students can obtain both mainland vocational qualification certificates and skill certificates recognized by Hong Kong and Macao through one assessment. Promote the mutual recognition of professional skill certificates in the GBA and remove the institutional barriers to talent mobility.

6.5. Cross-Regional Talent Mobility and Employment Docking

Build a cross-regional rail transit talent employment information platform to realize the sharing of talent demand information and employment resources. Carry out cross-regional campus job fairs, enterprise lectures, and internship employment docking activities. Promote the cross-regional mobility of talents and improve the employment quality and regional adaptability of graduates.

7. Empirical Results and Analysis

7.1. Operation Effect of the Collaborative Education Mechanism

After 18 months of pilot implementation in the GBA, the collaborative education mechanism has achieved remarkable practical effects. The key indicators before and after implementation are compared and analyzed, as shown in **Table 2**.

Table 2. Operation effect of collaborative education mechanism.

Evaluation Indicators	Before Implementation	After Implementation	Improvement Rate/Change
Enterprise participation enthusiasm	33.3%	91.6%	+58.3%
Per capita training cost of enterprises (yuan)	12,400	8340	-32.7%
Proportion of cross-regional cooperative colleges	14.3%	71.4%	+57.1%
Number of mutual recognition professional certificates	0	12	+12
Curriculum co-construction ratio between schools and enterprises	23.8%	85.7%	+61.9%
Teacher sharing and mutual employment ratio	19.0%	76.2%	+57.2%
Practical training base co-construction ratio	26.2%	80.9%	+54.7%
Graduate employment rate	86.2%	97.8%	+11.6%
Enterprise satisfaction with graduates	65.7%	94.3%	+28.6%

SPSS statistical analysis results: The paired sample t-test shows that all quantitative indicators have extremely significant differences before and after the implementation of the mechanism ($p < 0.01$), among which enterprise participation enthusiasm, per capita training cost, cross-regional cooperative college proportion and other indicators have extremely significant differences ($p < 0.001$), indicating that the improvement effect of the collaborative education mechanism on each core indicator is statistically significant.

The data shows that the collaborative education mechanism significantly improves the enthusiasm of enterprise participation, reduces the training cost of enterprises, breaks through cross-regional institutional barriers, promotes the in-depth development of school-enterprise cooperation, and significantly improves the quality of talent training and employment effect.

7.2. Stability Test of the Mechanism

The coefficient of variation method is used to test the operation stability of the

mechanism by calculating the discrete degree of each key indicator during the 18-month pilot implementation period (divided into 6 phases, 3 months per phase). The coefficient of variation (CV) of all key indicators is less than 10%, among which the CV of enterprise participation enthusiasm is 6.2%, the CV of per capita training cost of enterprises is 7.8%, the CV of graduate employment rate is 3.5%, the CV of enterprise satisfaction with graduates is 5.1%, the CV of curriculum co-construction ratio is 8.9%, the CV of teacher sharing and mutual employment ratio is 7.5%, and the CV of practical training base co-construction ratio is 8.3%.

The test results show that the collaborative education mechanism has high operation stability, reliability, and sustainability, and can be used for long-term promotion and application.

8. Discussion

This study constructs a systematic “government-university-enterprise-research” four-in-one collaborative education mechanism and a complete set of cross-regional implementation paths for digital-intelligent rail transit talents in the GBA. The empirical results show that the mechanism and paths effectively solve the core problems such as cross-regional institutional barriers, insufficient enterprise motivation, imperfect operation mechanism, and insufficient guarantee conditions in the current collaborative education.

The “three compensations and three sharings” motivation mechanism balances the interests of all parties, effectively stimulates the endogenous motivation of enterprise participation, and alleviates the long-standing problem of “schools being enthusiastic while enterprises being cold”. The “dual subject and three commons” operation mechanism standardizes the cooperation process, improves the cooperation efficiency, and realizes the deep integration of education chain and industrial chain. The cross-regional implementation paths realize the interconnection of courses, the sharing of teachers, the co-construction of bases, and the mutual recognition of qualifications, break through regional institutional barriers, and promote the free flow of educational resources and talents.

Compared with existing research, this study has three innovations: first, targeting the special institutional background of the GBA, it provides a targeted solution to cross-regional cooperation barriers; second, it constructs a systematic and complete collaborative education mechanism, realizing the unity of motivation, operation, guarantee, and evaluation; third, it is verified by large-sample empirical data, with obvious practical effects and high promotion value.

However, this study still has some limitations. The scope of cross-regional cooperation needs to be further expanded to Hong Kong and Macao vocational education institutions. The benefit distribution plan and risk sharing mechanism need to be further optimized and refined. In the future, we will continue to promote the construction of the “GBA Rail Transit Education Community”, improve the long-term operation mechanism of collaborative education, and provide stronger talent support for the digital-intelligent transformation and high-quality

development of rail transit in the GBA.

9. Conclusions

This study focuses on the practical demand for collaborative cultivation of digital-intelligent rail transit talents in the Guangdong-Hong Kong-Macao Greater Bay Area, constructs a systematic “government-university-enterprise-research” four-in-one collaborative education mechanism with “benefit sharing, risk sharing, responsibility co-bearing” as the core, and designs a complete set of cross-regional implementation paths including curriculum interconnection, teacher sharing, base co-construction, qualification mutual recognition, and talent mobility.

Empirical research shows that the mechanism and paths significantly improve the enthusiasm of enterprise participation, reduce the training cost of enterprises, break through cross-regional institutional barriers, improve the quality of talent training and employment rate, and obtain high enterprise satisfaction.

The research results provide an operable, reproducible, and extendable model for cross-regional collaborative education of rail transit talents in the GBA, promote the deep integration of education chain, talent chain, industrial chain, and innovation chain, and have important theoretical value and practical significance for serving the national strategy of the GBA and supporting the high-quality development of rail transit.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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