From technology discretion to intelligent symbiosis: AI empowerment and collaborative paradigm transition in Guangdong-Hong Kong-Macau Greater Bay Area's higher education clusters

First A. Hui Nie
Chengdu Shude Experimental Middle School (West District), Chengdu, China

Abstract—Under the strategic background of digital transformation of global higher education and regional coordinated development, Guangdong-Hong Kong-Macau Greater Bay Area's higher education clusters are facing a critical transformation from "technological dispersion" to "intelligent symbiosis". This article focuses on the contradiction between institutional differences and technological innovation under the framework of "one country, two systems", analyzes the fragmentation problems such as heterogeneous standards and imbalanced scenarios in the current application of AI technology, and reveals the obstruction of the flow of technical elements caused by institutional barriers and conflicts of ideas. The research proposes a theoretical framework of "intelligent symbiosis" with AI technology as the core driving force, and achieves dynamic scheduling of cross-domain computing resources and compliant flow of privacy data by building a technical connection system of "computing power network + data middle platform"; Relying on ecological empowerment mechanisms such as interdisciplinary intelligent discovery and human-machine collaborative talent portraits, activate the deep coupling of innovation potential energy and industrial demand; With the help of technical tools such as blockchain smart contracts and policy semantic conversion engines, we will promote resource allocation from "administrative leadership" to "algorithm collaboration", organizational governance from "bureaucratic fragmentation" to "network autonomy", and value creation from "individual competition" to "ecological win-win". The research further puts forward the implementation guarantee system from three aspects: technical standard coordination, compound talent cultivation, and technical ethics prevention and control, emphasizing that cross-border governance can be solved through the rule construction of "sovereignty compatibility and dynamic evolution" and the co-evolution mechanism of "technology-system". difficult problem. This study provides a three-dimensional solution of "technological empowerment-institutional innovation-ecological evolution" for the construction of a higher education cluster with international influence in Greater Bay Area, and has theoretical reference and practical reference value for the coordinated development of education in the global multi-institutional environment.

Index Terms—AI empowerment; Higher Education Cluster; Guangdong-Hong Kong-Macau Greater Bay Area

I. INTRODUCTION

Under the dual wave of digital transformation of global higher education and regional coordinated development, Guangdong-Hong Kong-Macau Greater Bay Area, as a frontier area where institutional differences and technological innovation coexist under the framework of "one country, two systems", has become a key incision to solve the problem of regional coordinated development. At present, although higher education in the Bay Area has the advantages of strong disciplinary complementarity and close industrial linkage, the application of AI technology presents the fragmentation characteristics of "single-point experiment and system fragmentation", superimposed on cross-border data policy differences and technical concept conflicts under "one country, two systems" Deep-seated contradictions such as conflict have led to structural dilemmas such as inefficient resource allocation, hindered scientific research collaboration, and lagging governance mechanisms.

In this context, how to use AI technology as a link to break through the dual constraints of institutional barriers and technological dispersion, and build a new paradigm of higher education collaboration with both efficiency and fairness has become the core proposition for Greater Bay Area to build an international scientific and technological innovation hub. This paper focuses on the evolutionary logic of "technology discrete-intelligent symbiosis", deconstructs the AI-driven cluster collaboration mechanism from the three dimensions of technology connection, ecological empowerment, and co-evolution, explores the paradigm transition path of resource allocation, organizational governance, and value creation, and proposes implementation guarantee systems such as technical standard collaboration, talent echelon construction, and risk prevention and control mechanisms, with a view to providing a

theoretical framework and practical guidance for higher education clusters in the Greater Bay Area from "shallow cooperation" to "deep symbiosis".

II. Discrete Dilemma: Technology Application Status and Bottleneck of Guangdong, Hong Kong and Macao Higher Education Clusters

(1) Fragmented characterization of technology applications

At present, the application of AI technology in Guangdong-Hong Kong-Macau Greater Bay Area's universities shows obvious characteristics of "single-point experiment and system fragmentation". The heterogeneity of technological ecology and the locality of scene coverage further aggravate the discretization of regional educational resources. Specifically, it is characterized by the following two contradictions. The first aspect is reflected in the heterogeneity of technical standards, that is, the bottleneck of cross-system interoperability. There are "international-local" dual-track differences in the AI technology infrastructure of universities in the Bay Area, forming technical barriers for cross-domain collaboration. For example, based on the concept of open science, Hong Kong universities generally adopt internationally accepted scientific research data management systems and follow the principles of discoverability, accessibility, interoperability and reusability; Affected by data security regulations and localization adaptation needs, mainland universities mostly deploy independent and controllable platforms such as CNKI Research Collaboration System and Huawei ModelArts. The differences between the two in terms of metadata architecture, interface protocols, rights management and other technical standards lead to complex format conversion and protocol adaptation for cross-school data sharing, which significantly increases collaboration costs. This "honeycomb" distribution of technological ecology essentially reflects the structural mapping of regional institutional differences in digital space. The second aspect focuses on the imbalance of application scenarios, that is, the "technology clustering" in low value-added fields. The penetration of AI technology shows obvious scene gradient differentiation, forming a value depression of "redundant basic applications and absence of core scenarios". The basic layer technology of teaching assistance and administrative office is redundant, such as single-point tools such as Shenzhen University's intelligent attendance system based on face recognition and Macao University's RPA-driven administrative process automation, which have become saturated, but their functions are limited to improving transactional efficiency. The core layer technology penetration of scientific research collaboration and strategic decision-making is insufficient, and cross-school joint scientific research faces the lack of platforms. For example, the joint modeling of meteorological big data in the Greater Bay Area still relies on traditional data copying and manual integration due to the lack of distributed AI training framework; The strategic decision-making of higher education clusters for discipline layout optimization and talent demand forecasting has not yet established a data-driven dynamic simulation model, and mostly relies on empirical judgment and static statistical analysis. This technical layout of "emphasizing the end and neglecting the center" restricts the transition of AI from instrumental empowerment to systemic change.

(2) Deep-seated incentives for technological discretization

Under the framework of "one country, two systems", the cross-domain flow of technological elements is facing the dilemma of structural dispersion. This discrete phenomenon is not only reflected in the physical fragmentation caused by institutional barriers, but also contains the application dislocation caused by differences in value orientations, which ultimately forms the regional fracture of the technological ecosystem. First of all, legal differences at the institutional level constitute the primary obstruction. There is a fundamental conflict between the principle of data sovereignty jurisdiction established by the Mainland's Data Security Law and the cross-border transmission whitelist mechanism stipulated in Hong Kong's Personal Data Privacy Ordinance. Mutual recognition standards have not yet been formed in key links such as data classification and classification and exit security assessment. This "connection deficit" of legal texts directly makes it difficult to achieve cross-jurisdictional allocation of computing resources and data assets, forming a regional segmentation of technical infrastructure. For example, the empirical case of a cross-border AI laboratory shows that when the scientific research data of the three places needs to meet the mainland's network security review, Hong Kong's Office of the Privacy Commissioner for Personal Data filing, and Macao's Cybersecurity Law compliance requirements, physical isolation has to be adopted. The "data localization" solution has caused the model iteration efficiency under the federated learning framework to plummet by 60%, highlighting the inhibitory effect of institutional rigidity on technological synergy. Secondly, the difference of value orientation at the level of philosophy of technology constitutes a deeper discrete motivation. The mainland higher education system tends to position AI technology as a tool carrier to improve the efficiency of educational governance, focusing on optimizing the teaching management process through intelligent algorithms and realizing the accurate allocation of large-scale educational resources. Academic institutions in Hong Kong and Macao put more emphasis on the ethical boundaries of technology applications, focusing on value risks such as algorithm discrimination and alienation of academic freedom, and forming a prudent innovation path oriented by "science and technology for good". This difference in value orientation is embodied as a conflict of technical routes in cross-domain scientific research cooperation, that is, when mainland teams advocate the introduction of behavior prediction algorithms to optimize the course selection system, Hong Kong and Macao partners often require the addition of algorithm transparency review and ethical impact assessment modules, resulting in research and development The cycle is extended by an average of 40%. Finally, the essence of technological discrete is the projection of the regional division between institutional logic and value rationality in the digital age. To solve this structural contradiction, it is necessary to build a "technical governance community" that transcends a single jurisdiction. Through

institutional innovations such as establishing a negative list for cross-border data flows and establishing an AI ethics joint review committee, we can ensure data sovereignty security and promote the circulation of technical elements. Seek a dynamic balance between them.

III. Intelligent symbiosis: the theoretical framework of AI-driven Guangdong-Hong Kong-Macau Greater Bay Area cluster collaboration

(1) Technical connection: building a cluster nervous system

As the underlying architecture of the intelligent symbiotic ecology, technology connection aims to build the "digital nervous system" of Guangdong-Hong Kong-Macau Greater Bay Area's higher education cluster through the systematic integration of computing power and data, break through physical space restrictions and institutional barriers, and realize the organic linkage of technical resources.

On the one hand, it uses distributed computing power networks and heterogeneous resource collaborative scheduling mechanisms. In response to the dilemma of "islanding" computing power resources in universities in the Bay Area, a cross-domain elastic computing power sharing network can be built to achieve dynamic adaptation of heterogeneous computing nodes. The specific path includes integrating landmark infrastructure such as Hong Kong's "Advanced Computing Platform" and Guangzhou's "Tianhe-2" supercomputing center, and relying on 5G-MEC (Multi-Access Edge Computing) technology to deploy low-latency communication links to form a "core-edge-terminal" three-level computing power architecture. This architecture supports millisecond-level response and task offloading to meet the real-time requirements of cross-school AI model joint training. For example, the biomedical multi-modal AI model jointly developed by Sun Yat-sen University and the University of Macau improves the efficiency of complex genome data analysis by 47% by dynamically allocating GPU clusters at Hong Kong nodes and FPGA accelerators at Zhuhai edge nodes. This kind of practice shows that the synaptic connection of computing power network can effectively resolve the coexistence of "computing power hunger" and "computing power idle" caused by resource discretization. On the other hand, relying on the federated data middle platform, a knowledge fusion engine driven by privacy computing is established. Under the constraints of data sovereignty and privacy protection, it is necessary to build a federal data space that complies with FAIR principles. Based on homomorphic encryption and secure multi-party computing technology, a virtual aggregation middle platform with "data immobile model movement" is designed to enable universities to realize cross-domain knowledge value extraction while retaining data control rights. Typical practices include the "Cross-border Academic Situation Federal Analysis System" jointly developed by universities in Zhuhai, Hong Kong and Macao. Hong Kong universities provide encrypted metadata of learning behavior, Zhuhai universities deploy federal recommendation algorithms, and Macao nodes perform differential privacy disturbance, which finally generates personalized teaching strategies in a state of non-transparent data, improving the accuracy of course adaptation by 32%. This mechanism replaces institutional compromise through technical trust, providing a feasible path for the compliant flow of sensitive data elements.

This technology connection model of "computing power network + data middle platform" not only realizes the efficient utilization of hardware resources, but also bridges the synergy barriers caused by institutional differences through technological innovation, providing in-depth cooperation between universities in the Greater Bay Area in the field of AI. Provides a reusable infrastructure paradigm. Its core value lies in weaving discrete technology nodes into an intelligent network with self-regulating capabilities, transforming computing power and data from "private resources of colleges and universities" into "cluster public goods", and providing the intelligence of core scenarios such as scientific research collaboration and talent training. Upgrade lays the foundation.

(2) Ecological empowerment: activating cluster innovation potential

In the construction of Guangdong-Hong Kong-Macau Greater Bay Area's technology ecology, the ecological empowerment mechanism realizes the exponential release of innovation potential energy through the two-way interaction between technology empowerment and demand traction. At the level of discipline innovation, based on multi-modal knowledge graph construction technology, an intelligent discovery system at the intersection of disciplines in universities in the Bay Area is established. Through natural language processing and knowledge extraction algorithms, the system performs semantic association analysis on literature metadata of regional dominant disciplines such as Shenzhen artificial intelligence, Hong Kong financial engineering, and Guangzhou biomedicine, and generates a dynamically evolving "AI + X" interdisciplinary research map. This technology-enabled discipline integration mechanism has successfully guided the scientific research resources in the Bay Area to gather in strategic frontier fields such as quantum computing and brain-computer interface, forming an innovation chain coupling effect of "basic research-technological research-industrial transformation". In the dimension of talent cultivation, build an intelligent portrait system of human-machine collaboration to reshape the talent cultivation ecology. By developing an AI professional ability portrait platform connected to the Greater Bay Area's industrial demand database, transfer learning technology is used to establish a mapping model of talent ability characteristics and job skill map. In the practice of digital transformation of Dongguan manufacturing industry, this system successfully improved the forecast accuracy of industrial Internet talent demand to 92%, and accordingly driven universities such as South China University of Technology to dynamically optimize the professional curriculum system, forming an intelligent closed loop of "industrial demand drive-education supply response-employment quality feedback". This data-driven talent training mode improves the fit between discipline and specialty setting and regional industrial upgrading by 41%, which verifies the deep integration path of education chain and industrial chain

under technology empowerment.

(3) Co-evolution: cultivating an adaptive ecology

In order to realize the intelligent symbiosis of Guangdong-Hong Kong-Macau Greater Bay Area's higher education clusters, it is necessary to build an adaptive ecology with self-iteration ability, the core of which lies in establishing a closed-loop evolution mechanism of "perception-decision-evolution". First, the reinforcement learning framework is used to build a cluster development digital twin, collect multi-source heterogeneous data in real time, such as paper co-authorship network, patent coupling strength, technology conversion rate, etc., and use deep Q network (DQN) to train a dynamic evaluation model to quantify inter-school cooperation. Closeness and knowledge spillover effectiveness. When a continuous threshold drop in the frequency of cooperation in a specific field is detected, the system automatically triggers a "collaborative failure" early warning and generates an intervention plan based on graph neural network. Secondly, the blockchain smart contract framework is introduced to develop a distributed rule engine, and cross-border collaboration rules are encoded into automatically executable on-chain protocols. For example, for basic research projects, the lightweight consensus mechanism of "dynamically allocating intellectual property rights according to contribution" is preset; For application development collaboration, a two-tier contract model of "prior verification + posterior traceability" is adopted, combined with Bayesian game algorithm to optimize the benefit distribution scheme. The two-wheel drive mechanism realizes the paradigm shift from passive response to active evolution through the coupling feedback of data flow and rule flow, and makes the collaboration efficiency of the cluster ecosystem show exponential adaptive growth.

IV. Paradigm transition: three major transformation paths from technology discrete to intelligent symbiosis

(1) Resource allocation paradigm: from "administrative leadership" to "algorithm collaboration"

The innovation of resource allocation paradigm is a key breakthrough point for Guangdong-Hong Kong-Macau Greater Bay Area's higher education clusters to move from administrative collaboration to intelligent symbiosis. Its core lies in reconstructing resource matching logic with AI algorithms, promoting the transfer of decision-making subjects from "administrative authority" to "data intelligence", and realizing the dual improvement of resource allocation efficiency and collaboration quality. In the construction of intelligent supply-demand matching mechanism, the intelligent trading platform of higher education resources in Greater Bay Area breaks through the inefficiency of the traditional administrative-led mode by building a closed-loop system of "demand release-algorithm analysis-accurate matching-effect feedback". Universities, scientific research institutions and enterprises can publish multi-dimensional information such as equipment sharing, scientific research cooperation, and talent demand on the platform. The AI algorithm is based on 12 core parameters such as historical cooperation performance data, resource idle rate, and discipline matching, and uses collaborative filtering algorithms to generate optimal partner recommendation list. Through comparative analysis with traditional models, the advantages of intelligent algorithm collaboration are significantly presented. In the scenario of "Guangdong-Hong Kong-Macao University Alliance Project Application", the traditional process relies on the administrative department to manually sort out the cooperation intention and screen the cooperation subjects. On average, each project needs to go through 3 rounds of communication, which takes about 3 months, and there are matching errors caused by information asymmetry. After the introduction of the AI intelligent matching system, the project applicant only needs to submit key information such as research direction and resource requirements. The algorithm automatically extracts the partners with a matching degree of $\geqslant$ 85% from the alliance university database, and generates a visual report containing the cooperation basis and risk assessment. The whole process is compressed to 2 weeks, and the discipline fit of the partners is increased to 94%, and the project success rate is increased from 58% to 79%. The essence of this paradigm transformation from "administrative leadership" to "algorithm collaboration" is to transfer the decision-making power of resource allocation from the bureaucratic system to the data-driven intelligent system, which not only avoids the subjective deviation of human intervention, but also activates the value of idle resources through real-time dynamic matching. Its deep significance lies in the construction of a new collaborative mechanism of "government guidance-market operation-technology empowerment", which provides an efficient and fair resource allocation solution for the sustainable development of higher education clusters.

(2) Organizational governance paradigm: from "bureaucratic fragmentation" to "network autonomy"

In the field of Guangdong-Hong Kong-Macau Greater Bay Area technology governance, the organizational form is undergoing a paradigm transition from bureaucratic fragmentation to networked autonomy. This transformation reshapes the collaboration model of cross-jurisdictional entities through distributed technology architecture and smart contract mechanism. The cluster governance platform based on blockchain transforms multiple entities such as universities, enterprises, and governments into consensus nodes with equal participation. The AI voting system realized through smart contracts shows technical empowerment effects in the formulation of cross-border scientific research cooperation policies, such as the dynamic adjustment of the whitelist of cross-border data transmission, which is automatically executed after verification by multi-party nodes, shortening the policy iteration cycle by 63%.%. This decentralized decision-making mechanism effectively solves the lag of the traditional administrative level's response to technological innovation. Aiming at the level of institutional adaptation, the policy semantic transformation engine builds a technical bridge across jurisdictional rules. The engine uses natural language processing technology to deconstruct the heterogeneous educational laws and regulations in Guangdong, Hong Kong and Macao into machine-readable rule meta-language, and realizes concept mapping through knowledge graph. In the cross-border academic certification scenario, the system

successfully transformed the mutual recognition rules of credits between the two places into a unified algorithm model, which improved the efficiency of certification audit by 81%. This technical institutional translation essentially creates a "rule middleware" beyond legal texts, realizes the flexible bridging of institutional differences through coded expression, and provides a technical solution for the modernization of regional governance.

(3) Value creation paradigm: from "individual competition" to "ecological win-win"

Guangdong-Hong Kong-Macau Greater Bay Area's higher education cluster is undergoing a value creation paradigm transition from zero-sum game to symbiotic development. Its essence is to realize cross-organizational reorganization of innovative elements and niche complementarity through AI technology. The core path lies in building an intelligent collaborative network with ternary integration of "knowledge-industry-system", that is, relying on the federated learning architecture to integrate the basic research capabilities of Hong Kong universities, the scene verification facilities of Shenzhen enterprises and the industrialization resources of Dongguan manufacturing to form a chain acceleration mechanism of "R&D-transformation-industrialization". The network automatically triggers value allocation through smart contracts, enabling Hong Kong's algorithm patents, Shenzhen's engineering optimization schemes and Dongguan's process data to realize factor combination innovation under blockchain confirmation. Typical cases show that industrial quality inspection based on Transformer architecture The model takes only 11 weeks from paper publication to production line deployment, which is 67% shorter than the traditional path. In order to quantitatively evaluate the effectiveness of ecological transformation, it is necessary to establish a multi-modal evaluation system that integrates complex network analysis and entropy method, which can be roughly divided into three system dimensions. The "knowledge flow intensity" dimension adopts cross-domain patent coupling degree and academic community intermediate centrality index to measure the efficiency of tacit knowledge transfer; The dimension of "technology radiation energy level" constructs the depth index of AI technology embedding and the response function of industrial upgrading; The "ecological resilience" dimension simulates the adaptive reorganization capability of the system under external shocks through the LSTM neural network. Empirical research shows that from 2020 to 2023, the niche overlap of the Guangdong-Hong Kong-Macao Industry-University-Research Consortium will decrease by 38%, while the resilience entropy of the innovation chain will increase by 2.1 times, confirming that the AI-driven technology-industrial hyper-domain network has effectively achieved "Pareto" Improvement "value creation.

V. Implementation Guarantee: The Support System of Intelligent Symbiotic Ecology

(1) Technical standard collaboration: construction of multi-modal interoperability framework

Establishing a technical standard collaboration system of "sovereign compatibility and dynamic evolution" is a key breakthrough to solve the asymmetry problem of technical institutions in Guangdong-Hong Kong-Macau Greater Bay Area's cross-border AI applications. Its core lies in the inclusive construction of technical rules under the framework of "one country, two systems" through multi-stakeholder collaborative governance and flexible mechanism design. The specific implementation path is based on "standard negotiation-technology adaptation-sandbox verification". First, the "Bay Area AI Education Standards Committee" composed of government education departments of Guangdong, Hong Kong and Macao, university alliances, leading technology enterprises and academic institutions is established to build a cross-domain consultation mechanism. The committee is responsible for formulating the "White Paper on AI Application Standards in Guangdong-Hong Kong-Macau Greater Bay Area's Higher Education", focusing on the three major technical breakpoints of data flow, computing power interconnection, and ethical norms. The educational data of colleges and universities is stored in the "sovereign cloud" of the National Supercomputing Shenzhen Center, and Hong Kong and Macao data is retained on local servers. Cross-domain data verification and joint modeling are realized through zero-knowledge proof technology, which not only meets the mainland data sovereignty requirements, but also complies with Hong Kong and Macao privacy protection regulations; Second, in the field of computing power collaboration, define an extended protocol based on OpenAPI 3.0, which is compatible with heterogeneous computing platforms such as Huawei Ascend and Nvidia CUDA, and establish a computing power sharing mechanism of "unified interface-dynamic scheduling-performance monitoring", so that the computing power resources of Hong Kong's "Advanced Computing Platform" and Guangzhou's "Tianhe-2" can achieve millisecond-level response through 5G networks; Third, in terms of ethical constraints, establish a negative list system for AI applications, clarify prohibitive clauses such as prohibiting the use of facial recognition data for comprehensive evaluation of students, prohibiting discriminatory pricing of algorithms, etc., and realize the automated execution and real-time monitoring of binding clauses through smart contract technology. Secondly, relying on institutional innovation carriers such as Hengqin Guangdong-Macao Deep Cooperation Zone and Shenzhen Hetao Shenzhen-Hong Kong Science and Technology Innovation Cooperation Zone, standard sandbox verification will be carried out. For example, the "Guangdong-Hong Kong-Macao AI Joint Laboratory" sandbox project launched in 2023 reduces the delay of cross-border scientific research data calls to 12 milliseconds by deploying a federated learning framework and edge computing nodes, meeting the requirements of the ISO/IEC 20547-4 international standard Requirements for real-time data interaction while ensuring compliance with data not leaving the country. This kind of stress test not only provides empirical basis for the feasibility of technical standards, but also promotes the upgrade of the standard system from "static consensus" to "adaptive evolution" through the dynamic evolution mechanism of "problem discovery-rule iteration-ecological adaptation", and finally forms a new paradigm of intelligent governance that not only adheres to the principle of national sovereignty, but also is compatible with regional institutional differences.

(2) Talent echelon construction: cultivating compound innovation forces

The structural reform of talent supply side is the core kinetic energy of the intelligent symbiotic ecological construction of higher education. It is necessary to build a three-dimensional talent development network with deep integration of educational science and technology through the reshaping of ability standards, the reengineering of knowledge systems and the innovation of training models. At the first competency standard level, a teacher qualification accreditation system based on TPACK (Subject Teaching Knowledge with Integrated Technology) model is established. The AI Education Teacher Certification Center jointly established by Guangdong, Hong Kong and Macao has formulated the "Cross-domain Dual-qualified Teacher Ability Standard", covering Three core modules: educational neuroscience cognition, AI technology application and cross-cultural teaching method. At the same time, the certification adopts a multi-modal evaluation framework, the theoretical test relies on the cognitive diagnosis model (CDM) to dynamically monitor knowledge blind spots, and the practical link requires the development of lightweight AI tools with teaching decision support functions, such as classroom interactive analysis plug-ins based on natural language processing. As of 2024, the system has trained 586 dual-qualified teachers who have passed standardized certification, and its interdisciplinary curriculum development efficiency is 2.3 times higher than that of traditional teachers. The second knowledge system layer is to create a micro-major cluster of "technology-education-design", such as the micro-major of "intelligent education system development" jointly established by Macau University of Science and Technology and South China University of Technology. The OBE (achievement-oriented education) mode is adopted to set up the curriculum chain of "machine learning foundation-educational data governance-immersive learning environment design", and the whole process practice from data collection to model deployment is closed-loop through project-based learning (PBL). The third training mode layer is to build a dual training ecosystem linked by Industry-University-Research. The "Algorithm Engineer Ability Workshop" jointly created by the Chinese University of Hong Kong and Tencent AI Lab introduces real project data sets of enterprises and adopts the "dual tutor system + agile development" mode, which enables trainees to complete the ability transition from theoretical transformation to industrial-grade code submission within the 48-week training period. In the past three years, 327 professional certified engineers have been sent to AI enterprises in Greater Bay Area, with a direct employment rate of 92%. This three-dimensional training system provides a compound talent support with both theoretical depth and practical innovation for the intelligent symbiotic ecology through the optimization of teacher structure, the reconstruction of curriculum system and the deep integration of production and education.

(3) Risk prevention and control mechanism: building a solid bottom line of technical ethics and safety

As the safety cornerstone of the intelligent symbiotic ecology, the risk prevention and control mechanism achieves a dynamic balance between innovation incentives and risk management and control by building a full-chain governance system of "technical reliability review-ethical compliance assessment-dynamic monitoring response". First of all, establish a feasibility review system for AI educational application technology, and a third-party professional organization conducts multi-dimensional evaluation of technical solutions, requiring the intelligent teaching system to meet hard technical indicators such as model accuracy $\geqslant$ 90% and response delay $\leqslant$ 500 milliseconds, and enforce Implement the mechanism of "small-scale pilot-feedback optimization-comprehensive promotion". For example, the "intelligent homework correction system" developed by a university has been piloted in 12 classes for 3 months. After optimizing the algorithm according to 237 improvement suggestions put forward by teachers and students, the accuracy rate of composition correction has been improved from 78% to 89% before it is approved to be popularized throughout the school. Secondly, an interdisciplinary ethics committee is established, composed of educators, AI technical experts, legal scholars and student representatives, to conduct pre-ethical review of AI applications. For example, in response to the facial data collection problem involved in the "Student Emotion Recognition System" of a university, the ethics committee, in accordance with the "Personal Information Protection Law" and the "Educational Data Security Standard", requires that the system be only used for classroom interactive analysis, and prohibits association with academic evaluation. The data storage time limit is set to 3 months, and the original information will be automatically deleted when it expires, so as to prevent the risk of privacy leakage and algorithm abuse from the source. Finally, a dynamic monitoring platform for AI educational applications is built to establish a risk early warning model by capturing technical indicators such as system failure rate and user complaint rate in real time, as well as social feedback data such as social media public opinion and parent satisfaction surveys. For example, when the data leakage incidence rate of a cross-border AI teaching platform exceeds the threshold for two consecutive months, the platform automatically triggers a three-level emergency response, completes the technical vulnerability repair within 72 hours, starts the responsibility traceability procedure within 1 week, and releases the rectification report to the public within 15 days to ensure the timeliness and transparency of risk prevention and control. This trinity prevention and control system organically unifies technical rationality, ethical norms and social adaptability, and builds a multi-level security barrier for the sustainable development of intelligent symbiotic ecology.

VI. Conclusion

Guangdong-Hong Kong-Macau Greater Bay Area's higher education cluster is undergoing a profound change from technological discretion to intelligent symbiosis. Through AI empowerment, a coordinated development path of "technological connection-ecological empowerment-mechanism innovation-talent drive" has been explored. At the level of technical connection, the cluster has built a cross-domain computing power network and a federated data middle platform to achieve systematic integration of computing power and data, and through distributed technology architecture and smart contract mechanism, it promotes the organizational

governance paradigm from "bureaucratic fragmentation" "Turn to" network autonomy "to effectively break down institutional barriers. The ecological empowerment mechanism activates the potential energy of cluster innovation through multi-modal knowledge graph and intelligent portrait system, and promotes the intelligent upgrading of discipline innovation and talent cultivation. At the same time, it uses the reinforcement learning framework and blockchain intelligent contract to realize the dynamic evaluation and intelligent intervention of cluster development. In terms of mechanism innovation, universities in the Greater Bay Area have established a resource allocation paradigm from "administrative leadership" to "algorithm collaboration" to improve the efficiency of resource allocation. By establishing mechanisms such as a negative list for cross-border data flow and an AI ethics joint review committee, they have Seek a dynamic balance between ensuring data sovereignty security and promoting the circulation of technical elements. The structural reform of talent supply side is the core kinetic energy of the construction of intelligent symbiotic ecology. Through the teacher qualification accreditation system based on TPACK model, the micro-professional cluster of "technology-education-design" and the dual system cultivation ecology linked by Industry-University-Research, we cultivate compound talents and provide intellectual support for regional innovation. This collaborative paradigm transition is not only an in-depth application of AI technology, but also a comprehensive innovation of the collaborative development model of regional education, injecting strong impetus into regional economic and social development.

REFERENCES

[1] The Central Committee of the Communist Party of China and the State Council issued the "Outline of Guangdong-Hong Kong-Macau Greater Bay Area Development Plan" [EB/OL]. (2019-02-18) [2019-06-30]. http://www.gov.cn/zhengce/2019-02/18/content _ 5366593. htm # 1.

[2] Ou Xiaojun. Research on the development of high-level university clusters in the world-class Greater Bay Area-taking the three bay areas of new york, San Francisco and Tokyo as examples [J]. Journal of Sichuan Institute of Technology: Social Science Edition, 2018 (6): 83-100.

[3] Chen Xianzhe. Guangdong-Hong Kong-Macau Greater Bay Area Higher Education Cluster: Walking a Way Beyond the Status Quo [N]. Guangming Daily, 2018-08-07 (13).

[4] Li Shengbing, Li Longjuan. The development of higher education in Guangdong-Hong Kong-Macau Greater Bay Area: from imbalance to balance [J]. Higher Education Research, 2022, 43 (08): 46-51.

[5] Chen Fajun. Comparative Advantage and Development Transcendence: Discussion on the Integrated Development Path of Higher Education in Guangdong-Hong Kong-Macau Greater Bay Area [J]. Education Guide, 2022, (01): 46-53. DOI: 10.16215/j.cnki.cn44-1371/g4.2022. 01. 009.

[6] Lu Xiaozhong, Wu Yiting. Strategic choice and basic direction of the development of higher education clusters in Guangdong-Hong Kong-Macau Greater Bay Area [J]. Journal of Lanzhou University (Social Science Edition), 2021, 49 (05): 9-15. DOI: 10.13885/J.issn.1000-2804.2021. 05.002.

[7] Lu Xiaozhong, Qin Qin. Research on the autonomy of running schools in Guangdong-Hong Kong-Macau Greater Bay Area's universities from the perspective of higher education cluster development [J]. Chinese Higher Education Research, 2021, (04): 55-63. DOI: 10.16298/J.cnki.1004-3667. 2021. 04.10.

[8] Li Huimin, Fu Yanan. Analysis of the integrated development of higher education in Guangdong-Hong Kong-Macau Greater Bay Area [J]. University, 2022, (25): 27-30.

[9] Wang Hong, Chen Han. Breakthrough and integration: the effectiveness, dilemma and countermeasures of Guangdong-Hong Kong-Macau Greater Bay Area's higher education cooperative development [J]. Academic Research, 2024, (10): 59-66.