



RESEARCH ARTICLE

CONSTRUCTION OF A PRACTICAL AND INNOVATIVE ABILITY TRAINING MODEL FOR ENVIRONMENTAL NEW ENGINEERING TALENTS UNDER THE BACKGROUND OF "DUAL CARBON" GOALS: A CASE STUDY OF HUNAN INSTITUTE OF TECHNOLOGY

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ABSTRACT

Driven by the national "Carbon Peak and Carbon Neutrality" strategy and the Ministry of Education's "New Engineering" initiative, the traditional training model for environmental engineering talents faces structural transformation pressure, urgently requiring a shift towards a new engineering paradigm that cultivates interdisciplinary knowledge integration capabilities, outstanding engineering practical abilities, and cutting-edge innovative thinking. Taking the environmental engineering program at Hunan Institute of Technology as an empirical research object, this study identifies core issues in current talent cultivation through systematic investigation and in-depth analysis, including curriculum systems lagging behind industrial technology iterations, scattered practical teaching resources disconnected from real engineering scenarios, lack of interdisciplinary knowledge integration mechanisms, and evaluation orientations emphasizing knowledge memorization over ability innovation. Based on this, a "Knowledge-Ability-Platform" trinity practical and innovative ability training model oriented towards the "Dual Carbon" goals is constructed. Through modular curriculum restructuring, building a "Four-Dimensional Integrated" practical teaching platform, implementing interdisciplinary project-driven teaching, and innovating multi-dimensional dynamic evaluation mechanisms, this model forms a closed-loop system that organically connects the education chain and talent chain with the industrial chain and innovation chain. Over three years of practice have shown that this model significantly enhances students' comprehensive literacy in low-carbon technology application, complex environmental problem-solving, and teamwork, with graduates demonstrating markedly improved employment competitiveness, scientific research transformation capabilities, and social service effectiveness, providing a referable and scalable reform paradigm for cultivating environmental new engineering talents in local application-oriented undergraduate institutions.

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INTRODUCTION

The environmental crisis triggered by global climate change has emerged as one of the most significant challenges facing humanity in the 21st century, posing severe threats to the stability of Earth's ecosystems and the sustainable development of human society. To actively address this global challenge and demonstrate the responsibility of a major power, China solemnly proposed the strategic goals of "achieving carbon peak before 2030 and carbon neutrality before 2060" (hereinafter referred to as the "Dual Carbon" goals) in 2020, integrating them comprehensively into the top-level design and strategic framework of national economic and social development [1]. The realization of these ambitious goals depends not only on disruptive low-carbon technological innovations, profound industrial restructuring, and energy system transformation but also fundamentally calls for a

strategic workforce of environmental new engineering talents equipped with interdisciplinary knowledge structures, outstanding engineering practical capabilities, and cutting-edge innovative thinking, whose quality and quantity will largely determine the progress and effectiveness of achieving the "Dual Carbon" goals [2]. However, examining the current status of environmental talent cultivation in Chinese universities, particularly local application-oriented undergraduate institutions, reveals significant structural disconnections and functional misalignments between the existing training models and the urgent demands of the "Dual Carbon" strategy. Traditional environmental engineering curriculum systems have long been structured around end-of-pipe pollution control technologies, focusing on treatment and disposal technologies for conventional pollutants in water, air, and solid waste, while failing to effectively incorporate knowledge and skill

requirements in emerging "Dual Carbon" fields such as carbon emission accounting, carbon capture, utilization and storage (CCUS), smart energy management, and life cycle assessment, resulting in obvious deviations between the knowledge structure of talent cultivation and the evolution direction of industrial technology^[3]. Practical teaching segments generally suffer from scattered resources, slow equipment updates, and weak connections to real engineering scenarios, making it difficult for students to access and master cutting-edge low-carbon technological equipment and process systems, thereby yielding unsatisfactory outcomes in practical and innovative ability cultivation. Against this backdrop, the "New Engineering" initiative promoted by the Ministry of Education explicitly proposes reform directions of "industry-education integration, cross-boundary interdisciplinary collaboration, and competency orientation," emphasizing the reconstruction of talent training systems centered on practical and innovative abilities and promoting the transformation of engineering education from "knowledge transmission" to "competency cultivation"^[4]. The "Guiding Opinions on Accelerating New Engineering Construction to Serve Carbon Peak and Carbon Neutrality Actions" issued by the Ministry of Education in 2023 further explicitly requires deeply embedding low-carbon technology modules into environmental and related disciplinary programs, strengthening school-enterprise collaborative education mechanisms, and constructing new talent training systems adapted to the demands of the "Dual Carbon" goals^[5].

Therefore, anchored at the intersection of the "Dual Carbon" strategy and new engineering construction, this study takes the environmental engineering program at Hunan Institute of Technology—a typical local application-oriented institution—as an empirical research object. Through systematic problem diagnosis, international experience reference, and localized innovation, it aims to construct a novel training model designed to comprehensively enhance students' practical and innovative abilities. By deeply analyzing the structural defects of existing training systems, scientifically designing systematic reform frameworks, elaborating specific implementation pathways, and objectively evaluating implementation effectiveness, this study seeks to provide feasible theoretical references and practical paradigms for similar local institutions to deepen teaching reforms and precisely deliver composite and innovative environmental engineering talents meeting national strategic demands. This study addresses three research questions: (RQ1) What are the structural deficiencies in current environmental engineering talent cultivation models under the "Dual Carbon" goals? (RQ2) How can a systematic training model be designed to integrate knowledge, ability, and platform dimensions? (RQ3) What evidence supports the effectiveness of this model in enhancing students' practical and innovative abilities?

Domestic and International Research Status and Problem Analysis

Domestic Research Progress: Under the dual drive of policy guidance and practical demands, domestic universities and scholars have conducted multi-dimensional theoretical explorations and practical attempts regarding the cultivation of practical and innovative abilities in environmental talents, mainly concentrating on the following aspects. In terms of practical teaching model innovation, universities have generally attempted teaching reform paths centered on project-

driven and industry-education integration approaches. Practice teaching based on Outcome-Based Education (OBE) philosophy and CDIO (Conceive-Design-Implement-Operate) engineering education models has been widely applied, emphasizing student outputs and whole-process engineering competency cultivation as goals while focusing on the organic integration of theoretical knowledge and engineering practice^[6]. Some universities have established "Dual Carbon Technology Practice Classes" or "Order-oriented Training Classes" through school-enterprise cooperation, introducing real projects such as environmental steward services for industrial parks, corporate carbon auditing, and cleaner production auditing into curriculum design and graduation design segments, enabling students to enhance comprehensive abilities through solving actual engineering problems^[7]. Additionally, interdisciplinary teaching models based on STEAM (Science, Technology, Engineering, Arts, and Mathematics) concepts have begun exploratory implementation in some universities, though they remain in the embryonic stage within environmental programs, with both the systematic nature of curriculum design and the maturity of teaching implementation awaiting further improvement^[8].

Regarding curriculum system and evaluation mechanism reforms, in response to curriculum content lagging behind technological development, scholars have proposed adding low-carbon technology modules to existing curriculum systems and integrating low-carbon concepts into professional foundation course teaching^[9]. In terms of assessment and evaluation methods, some universities have attempted to introduce diverse evaluation means such as project defenses, enterprise mentor scoring, and process-oriented assessment, attempting to break the traditional single evaluation model of "one examination determining grades." However, overall, the credit proportion of practical segments in environmental programs at domestic universities is generally low (mostly below 30%), written examinations remain the primary evaluation method, and effective evaluation mechanisms for students' engineering practical abilities, innovative thinking abilities, and teamwork capabilities have yet to be established^[10].

In terms of disciplinary competitions and innovation-entrepreneurship education, competitions such as the National College Students' Energy Saving and Emission Reduction Social Practice and Technology Competition, the "Internet+" College Students' Innovation and Entrepreneurship Competition, and the "Challenge Cup" Extracurricular Academic Science and Technology Works Competition have become important carriers and effective platforms for stimulating students' innovative enthusiasm and enhancing comprehensive abilities. Some outstanding competition projects (such as novel photocatalyst preparation, biomass energy conversion, and new battery material development) have achieved preliminary transformation into scientific research achievements, even incubating technology start-ups. However, student participation in disciplinary competitions usually covers a narrow scope, often concentrated among a small group of high-achieving students, and has not yet formed an inclusive mechanism of "promoting learning through Competition, promoting Teaching through Competition, and promoting Innovation through Competition"^[11]. In terms of interdisciplinary integration exploration, the "Multi-dimensional Industry-University-Research-Create New Engineering" model proposed by Xiamen University Tan Kah

Kee College attempts to integrate environmental science with energy engineering, big data analysis, and intelligent control to cultivate students' systematic thinking and comprehensive problem-solving abilities^[12]. However, systematic design of interdisciplinary courses, credit proportion (generally below 15%), and teaching organization and implementation still have considerable room for improvement, and disciplinary barriers have not yet been truly broken. In summary, although domestic research has achieved certain progress in certain segments or localized areas of talent cultivation, most have focused on reform attempts in single segments, lacking full-chain systematic training framework designs that penetrate curriculum system construction, practical teaching reform, platform resource integration, and evaluation mechanism innovation under the guidance of the "Dual Carbon" goals. Meanwhile, common problems persist, including laboratory equipment updates lagging behind industrial technology development, low coverage of virtual simulation platforms (approximately 30%), insufficient depth of school-enterprise cooperation (mostly remaining at the level of observation internships), and weak innovation orientation of evaluation mechanisms.

International Experience Reference: Developed countries have accumulated rich experience in engineering education and environmental talent cultivation, and their successful practices provide important reference value for local Chinese universities. Regarding project-driven deep practical models, the Technical University of Munich in Germany has integrated carbon management completely into the practical curriculum system through the construction of the "Industry 4.0-Lab" platform, where students complete carbon neutrality scheme design and energy system optimization projects for industrial parks under the guidance of enterprise mentors, achieving a smooth transition from theoretical learning to engineering practice^[13]. The University of California, Berkeley has established the "Carbon Neutrality Innovation Center," promoting students' direct participation in community low-carbon transformation and renewable energy projects, forming a closed-loop training model of "From Laboratory to Community," simultaneously enhancing students' sense of social responsibility and engineering practical capabilities^[14]. Regarding systematic interdisciplinary curriculum systems, Imperial College London offers courses such as "Low-Carbon Urban Systems Engineering" and "Energy and Environmental Policy," deeply integrating multidisciplinary knowledge including environmental science, energy engineering, urban planning, and economic management, with interdisciplinary courses accounting for up to 40%, effectively cultivating students' systematic thinking and comprehensive analysis abilities^[15]. Tokyo Institute of Technology in Japan cultivates students' abilities to solve complex environmental problems using artificial intelligence and big data technologies through courses such as "Environmental Big Data Analysis" and "Smart Environmental Monitoring," adapting to new capability requirements posed by digital transformation^[16].

Regarding close industry collaboration mechanisms, the University of Queensland in Australia has jointly established joint laboratories and research and development centers with mining giants such as BHP and Rio Tinto, where enterprises provide real R&D projects and technical challenges, and student research results are directly applied to production practice, with a high proportion of joint school-enterprise patent applications, forming a deep industry-university-

research integration mechanism^[17]. Delft University of Technology in the Netherlands generally implements a "Dual-Mentor System" (internal mentor + enterprise mentor), ensuring that training programs are synchronized with industrial technology development, with students' engineering practical capabilities and professional qualities receiving high recognition from enterprises^[18]. Regarding strong policy and resource support, the European Union funds universities to carry out carbon neutrality technology innovation projects and talent training reforms through research programs such as "Horizon Europe," and has established supporting "Green Skills" certification systems, providing clear capability standards and certification pathways for students' career development^[19]. The U.S. National Science Foundation (NSF) has special funds supporting universities in building advanced virtual simulation teaching platforms and interdisciplinary research centers, providing solid resource guarantees for innovative talent cultivation^[20].

International experience indicates that successful practical and innovative ability cultivation depends on four key elements: first, deep industry-education integration, establishing long-term mechanisms and benefit-sharing mechanisms for school-enterprise collaboration; second, systematic interdisciplinary integration, breaking traditional disciplinary barriers and constructing modular, cross-cutting curriculum systems; third, diverse competency evaluation, introducing external evaluation entities such as enterprises, communities, and industry organizations, and establishing evaluation mechanisms combining process-oriented and outcome-oriented assessment; and fourth, continuous policy guidance and adequate resource investment, optimizing educational resource allocation to provide institutional guarantees and material foundations for teaching reforms.

Analysis of Main Problems in Current Status: Based on comparative analysis of domestic and international contexts and field investigations at Hunan Institute of Technology, the main problems in current environmental new engineering talent cultivation at local Chinese universities can be summarized into three core contradictions. First, the structural contradiction between national strategic demands and educational supply. The realization of the "Dual Carbon" goals involves profound transformations across multiple systems including energy, industry, transportation, construction, and agriculture, requiring talents to master composite knowledge such as carbon emission accounting methodology, clean energy technology principles, low-carbon management systems, and carbon trading mechanisms. However, traditional environmental engineering curriculum systems still focus on end-of-pipe treatment technologies for water, air, and solid waste as the main framework, with a low proportion of low-carbon related courses (taking Hunan Institute of Technology as an example, only 12% in 2023), resulting in obvious disconnections between the knowledge structure of talent cultivation and industrial demands^[21]. Second, the contradiction between rapid industrial technology iteration and lagging updates of educational practical resources. The proposal of the "Dual Carbon" goals has spawned emerging professions such as carbon emission administrators, carbon asset managers, energy storage engineers, and hydrogen energy engineers, putting forward new requirements for the skill structure of talents. However, the update cycle for practical teaching equipment in universities is relatively long (often reaching 5-8 years), investment in virtual simulation platform

construction is insufficient and coverage is low, and school-enterprise cooperation bases provide limited continuous, high-level practical projects, making it difficult for students to access and master cutting-edge low-carbon technological equipment and process systems [22]. Third, the contradiction between interdisciplinary comprehensive capability requirements and single-discipline training models. Solving "Dual Carbon" related complex engineering problems requires integrating multidisciplinary knowledge including environmental science, energy engineering, big data analysis, economic management, and public policy, requiring students to possess systematic thinking and comprehensive analysis capabilities. However, existing training models remain confined within single disciplinary boundaries, with low proportions of interdisciplinary courses, scattered design, and lack of systematic nature, resulting in obvious deficiencies in cultivating students' systematic thinking and ability to solve comprehensive problems [23]. Additionally, problems such as evaluation systems emphasizing knowledge memorization over ability innovation, lacking effective measurement of students' innovative qualities and engineering practical capabilities, and shortages of "dual-qualified" teachers in the faculty who possess both solid theoretical foundations and rich practical experience in low-carbon technologies, collectively constrain the effective cultivation of practical and innovative abilities in environmental new engineering talents.

Training Model Construction: The Trinity Framework: In response to the aforementioned problems, Hunan Institute of Technology's environmental engineering program, based on in-depth investigation and systematic demonstration, has constructed a "Knowledge-Ability-Platform" trinity training model guided by the "Dual Carbon" goals and centered on practical and innovative ability cultivation, forming a systematic reform framework with clear objectives, distinct pathways, and strong guarantees.

Design Principles: The design of this training model follows four basic principles. The goal-orientation principle requires close alignment with the "Dual Carbon" strategy and national policy requirements, focusing on talent demands in low-carbon, zero-carbon, and negative-carbon technology fields, clarifying three-dimensional training objectives of knowledge, ability, and quality, and ensuring high consistency between talent cultivation and national strategies and industrial demands. The industry-education synergy principle emphasizes deepening comprehensive cooperation with industry enterprises, integrating real industrial projects, technical challenges, and engineering cases into the entire teaching process, constructing a closed loop of "Teaching-R&D-Practice-Application," and achieving organic connection between the education chain and industrial chain. The competency progression principle follows talent growth patterns and cognitive development laws, designing spiral, progressive competency cultivation paths from basic skill training to comprehensive application ability cultivation and then to innovative research ability enhancement, ensuring students' abilities progress step by step and continuously advance. The interdisciplinary integration principle actively breaks disciplinary barriers and professional boundaries, promoting cross-integration between environmental engineering and energy science, data science, management science, economics, and other disciplines, cultivating students' systematic thinking and comprehensive analysis capabilities,

enabling them to cope with challenges of complex engineering problems.

Core Elements and Model Architecture: The "Knowledge-Ability-Platform" trinity framework consists of three mutually supporting and synergistically interacting core elements. The knowledge layer serves as the theoretical foundation, systematically constructing a theoretical system covering traditional environmental engineering basic theories, low-carbon technology principles and methods, carbon neutrality policies and regulations, and interdisciplinary expansion knowledge, laying a solid knowledge foundation for students' ability development. The ability layer serves as the cultivation core, forging students' low-carbon technology application capabilities, complex engineering problem-solving capabilities, innovative design capabilities, teamwork capabilities, and lifelong learning capabilities through diversified teaching methods and practical segments, which constitutes the key output of the model. The platform layer serves as the support guarantee, integrating and constructing diversified platforms including on-campus laboratories, school-enterprise joint practice bases, virtual simulation centers, and disciplinary competition and innovation-entrepreneurship platforms, providing comprehensive resource support, environmental guarantees, and institutional incentives for knowledge transmission and ability transformation.

The three core layers, driven externally by the "Dual Carbon" strategic demands and new engineering construction requirements, form a mutually promoting and synergistically effective closed-loop system through organic linkage of implementation pathways such as curriculum system construction, practical platform building, teaching method reform, and evaluation mechanism innovation, jointly pointing to the core training objective of practical and innovative abilities. The architecture of this model is shown in Figure 1.

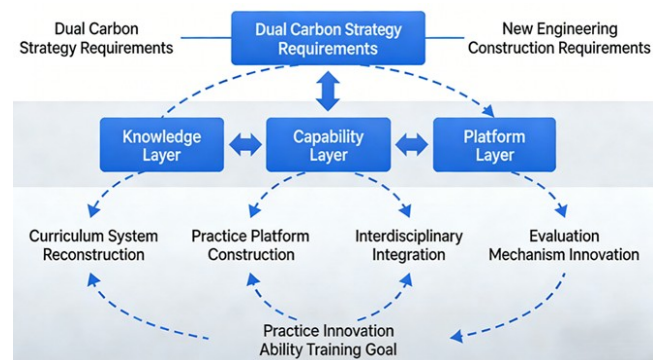


Figure 1. Architecture of the "Knowledge-Ability-Platform" Trinity Training Model

Implementation Pathways

Curriculum System Reconstruction: Building a "Modular-Interdisciplinary-Dynamic" New Curriculum System: As the core carrier of talent cultivation, the curriculum system of Hunan Institute of Technology's environmental engineering program has undergone systematic reconstruction, forming a modular curriculum architecture adapted to the demands of the "Dual Carbon" goals. Regarding the construction of low-carbon technology modules, core courses such as "Carbon Neutrality Technology and Practice," "Carbon Accounting and Trading," "Smart Environmental Monitoring," "Life Cycle

Table 1 Comparison of Curriculum System Before and After Reconstruction

Course Category	Credit Proportion Before Reconstruction	Credit Proportion After Reconstruction	Main Changes
Low-Carbon Technology Courses	12%	30%	Addition of courses such as carbon accounting, CCUS, and smart monitoring
Interdisciplinary Courses	8%	25%	Addition of courses such as big data analysis and energy systems engineering
Practical Teaching Segments	28%	35%	Increased hours for enterprise project training and virtual simulation experiments
Traditional Environmental Engineering Courses	52%	10%	Optimized integration with incorporation of low-carbon concepts and technologies

Table 2. Composition and Functions of the "Four-Dimensional Integrated" Practical Platform

Platform Dimension	Main Composition	Core Functions	Student Coverage
On-Campus Laboratories	Environmental monitoring, low-carbon technology, and virtual simulation laboratories	Basic skill training and frontier technology experience	100% student coverage
School-Enterprise Joint Bases	Over 150 enterprises and industrial park practice bases	Real project participation and engineering practical ability cultivation	80% student participation
Virtual Simulation Center	VR operation and maintenance systems, carbon neutrality simulation platforms, etc.	Safety of high-risk experiments and universalization of high-cost experiments	Coverage of 30% of core courses
Disciplinary Competition Platform	Organization and funding of energy saving and emission reduction, Internet+, and other competitions	Innovation ability stimulation and comprehensive quality improvement	60% student participation

Table 3. Composition and Weight Allocation of the Multi-Dimensional Evaluation System

Evaluation Dimension	Weight	Main Evaluation Content	Evaluation Entity
Process-Oriented Assessment	60%	Project reports, teamwork, experimental operations, discussion participation	Internal teachers
Enterprise Feedback	25%	Technical contribution, problem-solving, professional quality, teamwork	Enterprise mentors
Quantified Innovation Capability	15%	Technology proposals, patents and papers, competition awards, project incubation	Internal teachers + Industry experts

Table 4. Comparison of Student Competency Scores Between Experimental and Control Groups

Competency dimension	Experimental group (n=120) M (SD)	Control group (n=98) M (SD)	t	p	Cohen's d
Low-carbon technology application	4.32 (0.56)	3.78 (0.62)	6.45	<.001	0.92
Complex problem-solving	4.15 (0.61)	3.65 (0.58)	5.89	<.001	0.84
Interdisciplinary collaboration	4.28 (0.52)	3.45 (0.71)	9.12	<.001	1.34
Innovation design	4.05 (0.68)	3.52 (0.65)	5.67	<.001	0.80

Note. Scores range from 1 to 5. Cohen's d: 0.2 = small, 0.5 = medium, 0.8 = large effect size.

Assessment," and "Clean Energy Technology" have been added, increasing the credit proportion of low-carbon related courses from the original 12% to 30%, significantly enhancing the low-carbon characteristics and technological frontier nature of the curriculum system. Regarding the construction of interdisciplinary modules, interdisciplinary courses such as "Big Data Analysis for Environmental Applications," "Low-Carbon Urban Planning and Management," "Energy and Environmental Systems Engineering," and "Carbon Neutrality Policy and Law" have been established, explicitly requiring the credit proportion of interdisciplinary courses to reach 25%, effectively breaking disciplinary barriers and cultivating students' systematic thinking. Regarding the construction of dynamic update mechanisms, a curriculum revision committee composed of industry experts, alumni representatives, and internal teachers has been established, holding annual curriculum seminars to timely transform the latest horizontal project achievements (such as "Low-Carbon Upgrade and Transformation Case of ICEAS Process Wastewater Treatment Plant" and "Carbon Neutrality Technology Pathway Planning Case for Industrial Park") into teaching cases, ensuring teaching content is synchronized with industrial technology development [24]. Table 1 shows the comparison of curriculum system reconstruction. As shown in Table 1, the curriculum system reconstruction has achieved three significant transformations: substantial increases in credit proportions for

low-carbon technology courses and interdisciplinary courses, further strengthening of practical teaching segments, and decreased proportion but updated content for traditional environmental engineering courses through optimized integration. This reconstruction ensures high consistency between the knowledge structure of talent cultivation and the demands of the "Dual Carbon" goals.

Practical Platform Construction: Building a "Four-Dimensional Integrated" Three-Dimensional Practical Teaching Platform: As an important carrier for student ability cultivation, Hunan Institute of Technology has integrated internal and external resources to construct a "Four-Dimensional Integrated" three-dimensional practical teaching platform system. Regarding on-campus laboratory upgrades, special funds have been invested to update instruments and equipment in environmental monitoring laboratories and add experimental platforms related to low-carbon technologies, such as photocatalytic reactors, small-scale carbon capture demonstration devices, biomass pyrolysis experimental systems, and solar cell testing platforms, enabling on-campus experimental conditions to support experimental teaching needs related to low-carbon technologies. Regarding the deepening of school-enterprise joint bases, stable cooperative relationships have been established with over 150 environmental protection enterprises, energy enterprises, and

industrial parks, jointly building "Dual Carbon Technology Practice Classes," "Outstanding Engineer Training Bases," and "Joint Graduate Training Bases," ensuring continuous import of real enterprise projects into the teaching process, with the proportion of enterprise mentor participation in guidance not less than 40%, providing students with ample opportunities to participate in real engineering project implementation ^[25]. Regarding the expansion of the virtual simulation center, virtual simulation teaching resources such as "VR Operation and Maintenance System for Wastewater Treatment Plants," "Carbon Neutrality Factory Simulation Platform," and "Virtual Simulation Experiment for Air Pollution Diffusion" have been independently developed or introduced, covering approximately 30% of high-risk, high-cost, and irreversible experiments in core courses, enhancing teaching safety while reducing experimental costs and expanding the boundaries of students' practical experience. Regarding the driving force of disciplinary competition platforms, active organization and funding of student participation in high-level disciplinary competitions such as the National College Students' Energy Saving and Emission Reduction Social Practice and Technology Competition, the "Internet+" Innovation and Entrepreneurship Competition, and the "Challenge Cup" Extracurricular Academic Science and Technology Works Competition have been undertaken, establishing an incentive mechanism of "promoting Learning through Competition, promoting Teaching through Competition, and promoting Innovation through Competition," with competition participation coverage increased from the original 15% to over 60%. Table 2 shows the main composition and functions of the "Four-Dimensional Integrated" practical platform. The construction of the "Four-Dimensional Integrated" practical platform has achieved comprehensive integration and optimized allocation of practical teaching resources, providing students with progressive practical environments ranging from basic training to comprehensive application and then to innovative research, effectively supporting the realization of practical and innovative ability cultivation goals.

Interdisciplinary Competency Integration: Implementing a "Three-Step" Approach of "Curriculum Integration-Team Collaboration-Project Driving": Interdisciplinary competency cultivation is a core requirement of the "Dual Carbon" goals for new engineering talents. Hunan Institute of Technology has implemented a "Three-Step" strategy of "Curriculum Integration-Team Collaboration-Project Driving." At the curriculum integration level, interdisciplinary course packages such as "Environment+ Energy+ Data" and "Environment+ Management+ Policy" have been established, with teachers from different disciplinary backgrounds and enterprise experts jointly delivering courses using modular teaching methods, enabling students to naturally access and master multidisciplinary knowledge during the learning process. At the matrix mentor team construction level, interdisciplinary mentor groups composed of internal teachers from environmental engineering, energy engineering, computer science, economic management, and public policy, as well as engineers from environmental protection enterprises, energy enterprises, and consulting institutions, have been formed to jointly guide students' graduation designs, comprehensive experiments, and innovation-entrepreneurship projects, ensuring students receive guidance from multidisciplinary perspectives ^[26]. At the project-driven teaching level, real horizontal projects from governments or enterprises (such as "Carbon Neutrality Technology Pathway

Planning for a Certain Industrial Park," "Carbon Emission Inventory Compilation for a Certain City," and "Cleaner Production Audit for a Certain Enterprise") serve as carriers, requiring students to form interdisciplinary teams and propose comprehensive solutions from multiple dimensions including technical feasibility, economic rationality, environmental friendliness, and social acceptability, and complete scheme design, implementation, and evaluation under the guidance of mentor groups, enabling students to enhance interdisciplinary collaboration capabilities and systematic thinking abilities through solving real complex engineering problems.

Evaluation Mechanism Innovation: Establishing a Multi-Dimensional Evaluation System of "Process-Oriented Assessment + Enterprise Feedback + Quantified Innovation Capability": Scientific evaluation mechanisms serve as important levers for guiding teaching reforms and motivating student development. Hunan Institute of Technology has established a multi-dimensional dynamic evaluation system. Process-oriented assessment accounts for approximately 60%, covering multiple dimensions such as project report quality, teamwork performance, experimental operation standards, classroom discussion participation, and phased achievement presentations, comprehensively reflecting students' learning processes and competency development trajectories. Enterprise feedback accounts for approximately 25%, with enterprise mentors conducting comprehensive evaluations based on students' technical contributions, problem-solving capabilities, professional qualities, and teamwork performance in actual projects, introducing industry standards and employer perspectives. Quantified innovation capability accounts for approximately 15%, establishing a series of quantifiable innovation indicators such as "number of low-carbon technology improvement proposals submitted," "participation in patent applications or paper publications," "level of disciplinary competition awards," and "incubation of innovation-entrepreneurship projects," objectively evaluating students' innovation achievements ^[27]. This multi-dimensional evaluation system breaks the traditional single evaluation model of "one examination determining grades," placing greater emphasis on evaluating students' practical abilities, innovative abilities, and comprehensive qualities, effectively guiding the transformation of teaching methods and the optimization of student learning behaviors. Table 3 shows the composition and weight allocation of the multi-dimensional evaluation system.

The establishment of the multi-dimensional evaluation system has achieved transformations from "knowledge evaluation" to "competency evaluation," from "outcome evaluation" to "process evaluation," and from "single evaluation" to "diverse evaluation," providing scientific guidance and incentives for practical and innovative ability cultivation.

Implementation Effectiveness Analysis: A Case Study of Hunan Institute of Technology: Since the implementation of the "Knowledge-Ability-Platform" trinity training model, Hunan Institute of Technology's environmental engineering program has achieved significant results in talent cultivation quality, teaching reform depth, and social service breadth, validating the effectiveness and replicability of this model.

Significant Improvement in Students' Comprehensive Abilities: Regarding practical and innovative abilities, student enthusiasm and coverage for participating in school-enterprise

cooperation projects and disciplinary competitions have substantially increased. Over the past three years, environmental engineering students have won more than 20 awards in national and provincial disciplinary competitions, applied for 15 patents, and published over 10 academic papers, with both quantity and quality of innovation achievements achieving notable improvements. For example, the "TiO₂/Diatomite Composite Photocatalyst" developed by a student team has been successfully applied in local wastewater treatment demonstration projects, achieving transformation from laboratory research to engineering application; the "Carbon Neutrality Technology Pathway Planning for a Certain Industrial Park" project participated in by students was adopted by local governments, becoming a guiding document for regional low-carbon development^[28].

Regarding employment competitiveness, graduates' major-matched employment rates and employment quality have significantly improved, particularly receiving widespread welcome from employers in emerging fields such as carbon auditing, carbon asset management, environmental consulting, clean energy, and environmental protection equipment manufacturing. Enterprise feedback indicates that graduates' job adaptation periods have shortened from the original 3-6 months to 1-2 months, with engineering practical abilities and problem-solving capabilities receiving high recognition from employers, and starting salary levels increasing by an average of 15% compared to pre-reform levels.

Regarding interdisciplinary collaboration capabilities, through comprehensive project training and interdisciplinary team practice, the vast majority of students can effectively organize and coordinate interdisciplinary teams, use multidisciplinary tools and methods to analyze and solve complex regional environmental problems, with systematic thinking and comprehensive analysis capabilities achieving notable enhancement. Graduate tracking surveys show that over 85% of graduates believe interdisciplinary training has been helpful for their career development.

Abundant Fruits of Teaching Reform: Regarding curriculum system optimization, a modular course group characterized by the "Dual Carbon" goals has been successfully constructed, with three characteristic textbooks published, including "Carbon Neutrality Technology and Practice" and "Big Data Analysis for Environmental Applications," and over 20 typical teaching cases developed, among which five cases have been rated as provincial excellent teaching cases, with curriculum construction achievements receiving recognition and promotion from peer experts. Regarding practical platform expansion and upgrades, the "Four-Dimensional Integrated" practical platform operates effectively, with annual per-student practical hours increasing from the original 120 hours to 180 hours, and practical teaching conditions achieving fundamental improvements. The number of school-enterprise joint bases has increased from the original 30+ to over 150, with cooperation depth elevated from the level of observation internships to joint training and collaborative R&D, achieving leapfrog improvements in both quantity and quality of practical teaching resources^[29].

Regarding evaluation mechanism scientification, the multi-dimensional evaluation system has been fully implemented, covering all professional courses and practical segments, breaking the traditional pattern of "one examination determining grades," and more comprehensively, objectively,

and dynamically reflecting students' comprehensive qualities and development potential, effectively guiding the transformation of teaching methods and the optimization of student learning behaviors.

Emerging Effects in Social Service and Research Transformation: Regarding technology achievement implementation, multiple technology achievements jointly developed by teachers and students (such as "Low-Cost Rural Wastewater Ecological Treatment Technology," "Industrial Wastewater Advanced Treatment and Resource Recovery Technology," and "Biomass Waste Energy Utilization Technology") have been promoted and applied locally, serving over 50 local enterprises, generating economic benefits exceeding 20 million yuan, while producing good environmental benefits and carbon reduction effects, receiving high praise from local governments and enterprises. Regarding deepened industry-university-research integration, through co-construction of bases, joint research projects, and shared resources, the connection between the university and local industries has become closer, forming a virtuous cycle mechanism of joint talent cultivation, joint process management, shared achievements, and shared responsibilities. Over 20 scientific research projects have been jointly applied for with enterprises, over 30 graduate students have been jointly trained, over 40 papers have been jointly published, and 25 patents have been jointly applied for, with both depth and breadth of industry-university-research cooperation reaching new levels^[30]. Although significant achievements have been made, challenges remain in the implementation process. Full curriculum coverage of virtual simulation platforms has not yet been achieved, with virtual simulation resources for some courses still requiring further development; high-level "dual-qualified" teaching teams still need expansion, particularly the shortage of enterprise part-time teachers with rich practical experience in low-carbon technologies; and continuous access to stable policy and funding support to ensure the sustainable development of the model still requires further efforts. These issues will be the key breakthrough directions for the next stage of reform.

DISCUSSION

International Dialogue and Theoretical Implications: While the proposed model has been developed to address the specific policy demands of China's "Dual Carbon" strategy, its underlying design principles are found to be consistent with global trajectories in engineering education reform. The pronounced emphasis on interdisciplinary competency development is observed to resonate closely with the "T-shaped engineer" concept articulated by the Massachusetts Institute of Technology^[31], which advocates for the integration of deep disciplinary expertise with broad cross-functional capabilities. However, a notable divergence from Western educational paradigms is identified: whereas individual innovation is frequently prioritized in Anglo-American models, the present framework places greater emphasis on collective achievement and social responsibility, thereby reflecting Confucian educational values that underscore communal harmony and ethical obligation^[32]. This cultural specificity raises critical questions regarding the transferability of the model to alternative national contexts, particularly those characterized by individualistic cultural orientations. From a theoretical standpoint, the "Knowledge-Ability-Platform" trinity framework is constructed through the integration of

constructivist learning theory^[33], experiential learning theory^[34], and social cognitive theory^[35]. Such theoretical pluralism is considered to address a significant limitation identified in the extant literature, namely the tendency toward single-theory approaches that inadequately capture the complexity of engineering learning environments^[36]. The synergistic interaction among knowledge acquisition, ability development, and platform support is posited to create a holistic ecosystem in which each dimension reinforces the others, thereby producing learning outcomes that exceed the additive effects of isolated interventions.

Practical Implications: The findings derived from this investigation yield several implications of practical significance for diverse stakeholders engaged in engineering education reform.

For Policymakers and Institutional Leaders: The successful implementation of the proposed model is contingent upon sustained institutional commitment and the strategic allocation of resources. As emphasized in recent engineering education reform blueprints^[37], dynamic curricula that balance disciplinary breadth and depth—while simultaneously cultivating capabilities aligned with future engineering visions, including adaptability, social responsibility, and digital literacy—cannot be achieved without dedicated funding mechanisms and systematic national skills planning. The Chinese experience demonstrates that alignment between industrial policy and educational policy is regarded as essential for creating enabling environments that support the widespread and sustainable adoption of educational innovations. Furthermore, the integration of "Dual Carbon" goals into engineering curricula is observed to provide a replicable model for embedding sustainability as a fundamental engineering principle rather than an elective add-on^[38], thereby addressing the persistent challenge of fragmented sustainability education documented in engineering programs worldwide.

For Educational Administrators: The expansion of school-enterprise partnerships from 30 to more than 150 collaborations within a three-year period illustrates that institutional barriers can be overcome through the strategic alignment of stakeholder interests. It is recommended that administrators prioritize the development of "dual-qualified" teaching teams, recognizing that faculty development in digital technologies and industry practices is indispensable for effective curriculum integration. The construction of integrated teaching materials that synthesize traditional engineering knowledge with emerging digital technologies—such as those combining environmental engineering with artificial intelligence—should be facilitated through cross-disciplinary collaboration and the deployment of modern information technologies, including virtual and augmented reality^[39].

For Engineering Educators: The "Three-Step" interdisciplinary competency integration strategy is put forward as a replicable approach to dismantling disciplinary silos. The matrix mentor team model, which combines internal faculty with industry experts, is identified as an effective mechanism for maintaining curriculum relevance while operating under resource constraints. Educators should note that the allocation of 60% weighting to process-oriented assessment represents a substantial departure from traditional examination-focused evaluation, necessitating parallel investments in assessment literacy and the development of

standardized rubrics. Moreover, the expansion of virtual simulation centers to cover 30% of high-risk, high-cost experiments demonstrates how digital transformation can enhance educational accessibility and safety while simultaneously reducing operational costs^[40].

Limitations and Future Research: Several limitations of the present study are acknowledged. First, by virtue of its single-institution case study design, the generalizability of the findings to research-intensive universities or alternative national contexts cannot be assumed. Second, the absence of a control group is recognized to constrain the capacity for causal inference regarding the model's effectiveness. Third, the partial reliance on self-reported data is understood to introduce potential response bias. It is therefore recommended that subsequent research employ multi-institutional comparative designs complemented by objective competency assessments.

Future Research Directions: Drawing upon the findings and acknowledged limitations of this investigation, four priority directions for future inquiry are proposed.

Digital Transformation and Artificial Intelligence Integration: The rapid advancement of generative artificial intelligence is regarded as presenting both opportunities and challenges for engineering education^[41]. Future research should be directed toward investigating how AI-driven personalized learning systems can be integrated into the "Knowledge-Ability-Platform" framework to enhance adaptive learning and competency assessment. Specific attention should be given to the development of AI literacy frameworks for engineering educators and students, the pedagogically aligned integration of AI tutors into learning management systems, and the ethical implications of generative AI in engineering problem-solving contexts.

Regional Collaborative Innovation Networks: The formation of regional "Low-Carbon Technology and Education Alliances," as proposed in this study, necessitates systematic investigation. Research should be conducted to examine governance models for multi-institutional collaborative networks, resource-sharing mechanisms and intellectual property arrangements, and standardized competency frameworks for carbon neutrality education across institutional boundaries.

Long-term Impact Assessment: Longitudinal studies tracking graduates over 5-10 year periods are considered essential for validating the sustained effectiveness of the training model. Priority research questions should address career trajectories and leadership development in carbon-related industries, the relationship between interdisciplinary training and innovation outcomes in professional practice, and the sustainability of competency development over time.

Cross-Cultural Adaptation and Transferability: In light of the cultural specificity identified in the present model, comparative research is required to test the model's applicability in diverse national contexts and educational systems, to identify cultural boundary conditions for the emphasis on collective achievement versus individual innovation, and to develop adaptation frameworks that integrate Confucian educational values with Western engineering education models.

Conclusion and Outlook

The "Knowledge-Ability-Platform" trinity environmental new engineering talent practical and innovative ability training model constructed and implemented by Hunan Institute of Technology around the demands of the "Dual Carbon" strategy has effectively alleviated core contradictions between talent cultivation and industrial demands, achieving organic connection between the education chain, talent chain, and industrial chain, innovation chain. Through systematic curriculum system reconstruction, three-dimensional practical platform construction, deep interdisciplinary integration, and scientific multi-dimensional evaluation innovation, this model has significantly enhanced students' practical and innovative abilities, interdisciplinary collaboration capabilities, and employment competitiveness, providing a referable and scalable reform paradigm for environmental new engineering talent cultivation at local application-oriented undergraduate institutions. Looking forward, to further deepen this model and expand its effectiveness, continuous efforts can be made in the following aspects. First, digital empowerment. Vigorously develop AI-driven smart education platforms and virtual simulation experiment projects, achieving full-cycle tracking and personalized guidance of students' learning processes, utilizing big data technology to analyze student learning behaviors and competency development trajectories, providing data support for teaching improvements, and comprehensively enhancing the depth, breadth, and precision of practical teaching. Second, regional collaborative innovation. Take the lead or deeply participate in forming regional "Low-Carbon Technology and Education Alliances," integrating high-quality resources from governments, enterprises, universities, and research institutes within the region, jointly formulating talent training standards, sharing practical teaching resources, and tackling key technical challenges, forming new patterns of regional collaborative education. Third, teaching team quality improvement. Implement "dual-qualified" teacher cultivation and recruitment plans, establish long-term mechanisms for teachers to undertake temporary posts in enterprises, improve the appointment and incentive mechanisms for enterprise part-time teachers, and build a high-level teaching team with reasonable structure, outstanding capabilities, and appropriate combination of full-time and part-time members. Fourth, strengthened policy guarantees. Actively appeal for and strive for greater inclination and support from governments at all levels in financial investment, project approval, and evaluation standards for "Dual Carbon" new engineering construction, creating favorable external environments and institutional guarantees for the deepening and promotion of the reform model. Hunan Institute of Technology's exploration and practice have proven that local application-oriented universities are fully capable and responsible to act proactively and contribute to serving national major strategies. The training model constructed provides valuable reference for similar institutions. Through continuous reform, innovation, deepening, and improvement in the future, it will surely be able to deliver more high-quality, composite, and innovative environmental new engineering talents for the smooth realization of China's "Dual Carbon" goals, making greater contributions to building a beautiful China and achieving sustainable development.

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