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Exploring Interdisciplinary Collaborative Training Models for Graduate Students in the Context of the "Dual Carbon" Goals

Shuang Chen[1], Jia Zeng[2], Hongmei Xie[2], Guilin Zhou[1,2]

[1]Engineering Research Center for Waste Oil Recovery Technology and Equipment, Ministry of Education, Chongqing Technology and Business University, Chongqing, 400067, China

[2]School of Environment and Resources, Chongqing Technology and Business University, Chongqing, 400067, China

ABSTRACT

This paper explores innovative pathways for interdisciplinary collaborative training models for graduate students, addressing the current shortage of high-level, multidisciplinary talent in light of China's major strategic goals of "carbon peaking and carbon neutrality." The study first analyzes the new demands these dual carbon targets place on talent's knowledge structure, innovation capabilities, and comprehensive competencies, highlighting the limitations of existing single-discipline training models in tackling complex systemic environmental and energy challenges. It then proposes establishing a collaborative training framework oriented toward "dual carbon" needs, integrating knowledge from multiple disciplines including energy, environment, economics, management, and policy. Specific reform measures are suggested, such as optimizing interdisciplinary curricula, building industry-academia-research-application practice platforms, forming cross-disciplinary mentor teams, and innovating project-driven teaching mechanisms. This model aims to break down disciplinary barriers, promote knowledge integration and capability consolidation, and provide theoretical reference and practical paradigms for cultivating specialized "dual carbon" professionals equipped with multidisciplinary perspectives, systems thinking, and collaborative innovation capabilities.

KEYWORDS

Carbon peaking and carbon neutrality; Interdisciplinary; Multidisciplinary talent; Teaching reform

1 Introduction

The comprehensive, systematic, and pervasive knowledge systems formed through interdisciplinary integration and convergence can effectively address the new problems and challenges facing human society. At the Central Conference on Talent Work, General Secretary Xi Jinping emphasized the need to "pursue an independent path in talent cultivation" and "foster more high-level, multidisciplinary talents with the potential to become strategic scientists." The report of the 20th CPC National Congress for the first time integrated the coordinated development of education, science and technology, and talent, explicitly highlighting the organic connection among "science and technology as the primary productive force, talent as the primary resource, and innovation as the primary driving force" [1-2]. Cultivating high-level, multidisciplinary talents has become a crucial pillar for resolving critical bottlenecks in key fields and building a science and technology powerhouse with a strong talent base. This has also propelled interdisciplinary talent development into a key direction for reforming graduate education in universities [3].

However, the discipline-based organizational structure widely adopted by modern universities has become increasingly fragmented as academic specialization deepens, solidifying disciplinary boundaries and creating relatively closed academic barriers [4]. Against this backdrop, interdisciplinary educational practices aimed at breaking down disciplinary boundaries face a certain institutional irony: their original intent was to dissolve knowledge gaps and organizational barriers between disciplines, yet they inevitably remain constrained by the inherent limitations of the university's existing organizational structure [5]. This contradiction is particularly pronounced within China's unique disciplinary institutional framework—where departmental structures, disciplinary development, and resource allocation form a highly rigid interlocking mechanism, creating profound tension between interdisciplinary practices and inflexible disciplinary systems [6]. Therefore, advancing interdisciplinary graduate education fundamentally calls for structural transformation within higher education organizations: it requires breaking down the closed state of traditional academic organizations while simultaneously reconstructing interdisciplinary organizational connections. Through institutional innovation, a corresponding training model must be established to provide sustainable institutional safeguards for interdisciplinary education [6]. Achieving the "dual carbon" goals is a complex endeavor encompassing energy system transformation, ecological restoration, and socioeconomic system reform. It necessitates the construction of a new ecosystem featuring the coordinated development of "energy-information-nature-society."

2 The necessity of interdisciplinary collaborative education

2.1 The urgent need to serve the national "dual carbon" strategic goals

The "dual carbon" goals (carbon peaking and carbon neutrality) represent China's core strategy for achieving a green, low-carbon transition, involving systemic transformations such as energy structure optimization, industrial upgrading, and ecological governance. Achieving these goals urgently requires support from multidisciplinary, innovative talent, while traditional single-discipline training models struggle to address the complex technical, policy, and management challenges in the “dual carbon” domain. Through interdisciplinary collaborative training, knowledge from multiple fields —including energy, environment, economics, materials, and information technology—can be integrated to build a cross-disciplinary system tailored to “dual carbon” needs, thereby providing high-level talent support for national strategic objectives.

2.2 The practical need to break through traditional disciplinary barriers

Graduate education currently remains characterized by disciplinary fragmentation, exhibiting issues such as overly narrow specializations, insufficient interdisciplinary integration, and lagging knowledge convergence. Addressing the dual carbon challenges demands multidisciplinary collaboration. For instance, developing new energy technologies requires integrating materials science with engineering applications, while managing carbon emissions necessitates combining economics with policy analysis. By exploring interdisciplinary collaborative training models, we can break down disciplinary barriers, promote knowledge exchange and skill integration, and cultivate versatile talents equipped with systematic thinking and cross-boundary collaboration capabilities.

2.3 An inevitable choice in responding to global technological and industrial transformation

Globally, green and low-carbon technologies are emerging as the core driving force behind the new wave of technological revolution and industrial transformation. Developed nations in Europe and America have already seized the high ground in cultivating talent for the “dual carbon” goals through interdisciplinary educational models, such as MIT's Energy and Environment Interdisciplinary Program. China urgently needs to benchmark against international best practices, establish a localized interdisciplinary training system, enhance the international competitiveness of graduate students in areas like green technology innovation and carbon trading mechanism design, and thereby contribute to achieving self-reliance and strength in science and technology.

2.4 key pathways for deepening industry-academia-research integration

Achieving the dual carbon goals requires collaboration among universities, research institutions, enterprises, and government agencies. Interdisciplinary collaborative training models can integrate academic research with corporate needs through mechanisms such as joint university-industry projects, dual-mentor systems, and industrial practice bases. For instance, project-based teaching focused on practical challenges like carbon capture technology development and low-carbon urban planning not only enhances students' ability to solve complex engineering problems but also accelerates the transformation of research outcomes to serve regional green economic transitions.

2.5 The intrinsic requirements for optimizing graduate education quality

The Chinese Ministry of Education's “Opinions on Accelerating the Reform and Development of Graduate Education in the New Era” explicitly calls for advancing interdisciplinary integration and industry-education collaboration in talent cultivation. Through interdisciplinary training reforms under the dual-carbon framework, we can drive curriculum restructuring (e. g., introducing cross-disciplinary courses like “Carbon Accounting and Carbon Finance” and “Smart Energy Systems”), teaching methodology innovation (e.g., case-based instruction and blended virtual-physical simulation experiments), and evaluation mechanism optimization (e. g., multidimensional achievement recognition). This will comprehensively enhance graduate students' innovation capabilities and practical competencies, providing a paradigm reference for cultivating high-level talent in the new era.

3 Building a high-quality collaborative training system

3.1 Analyzing interdisciplinary integration in graduate education under the “dual carbon” context

The “dual carbon” strategy has created multidisciplinary innovation opportunities in pollution control, primarily manifested in four dimensions: ① Digital Detection: Leveraging IoT, blockchain, and AI technologies to build a carbon footprint monitoring system, enabling precise carbon emission tracing and trustworthy data storage, thereby providing an intelligent support platform for carbon accounting and trading; ② Systemic Governance: Moving beyond traditional end-of-pipe treatment, establishing a multi-pollutant coordinated prevention and control system to form a full-chain management paradigm encompassing “source containment, process optimization, and end-of-pipe treatment”; ③ Green Technology: Driving low-carbon transformation in high-carbon industries like metallurgy and chemicals through innovative materials and processes, developing low-energy equipment and clean production technologies; ④ Energy Innovation: Accelerate breakthroughs in Carbon Capture, Utilization, and Storage (CCUS) technologies to advance deep decarbonization of energy systems. Against this backdrop, the core challenge in interdisciplinary graduate education lies in fostering deep internalization and innovative reconstruction of multidisciplinary knowledge. This project focuses on researching mechanisms for interdisciplinary knowledge integration, addressing the challenge of fragmenting knowledge systems, and laying the theoretical foundation for constructing a training pathway driven by demand, knowledge reconstruction, and capability leap.

3.2 Selection and development of interdisciplinary training content for graduate students in the context of the “dual carbon” goals

To address variations in graduate students' disciplinary backgrounds, research interests, and innovative capabilities, an interdisciplinary training system emphasizing “strong foundations, broad interdisciplinary exposure, and innovation-driven development” should be established. This will be achieved through coordinated implementation of tiered and categorized training, modular course design, project-driven practice, and flexible institutional frameworks: - Tailor “Environmental Engineering Plus” differentiated programs based on talent needs, integrating cross-disciplinary modules in mechanical engineering, energy, chemical engineering, etc.; Develop a three-tiered curriculum cluster of “Core + Expansion + Practice,” embedding academic seminars and industrial training within dual-carbon projects to form a “Professional Foundation - Interdisciplinary Expansion - Innovation Enhancement” training chain; Through a cross-disciplinary project repository, students undergo full-cycle training in “topic selection-team formation-problem solving,” facilitating knowledge transfer and industry alignment. Concurrently, a course marketplace and credit transfer system establish interdisciplinary innovation credit modules, dismantling disciplinary barriers and activating synergistic multi-platform resources to ultimately achieve personalized educational goals.

3.3 Research and implementation of interdisciplinary collaborative training mechanisms for graduate students in the context of the “dual carbon” goals

Under the “dual carbon” strategy, it is essential to transcend the limitations of the traditional single-mentor system and establish a “multi-disciplinary mentor group collaborative guidance” mechanism. This involves forming interdisciplinary teams comprising mentors from fields such as environmental science, energy, and chemical engineering. Within these teams, academic mentors provide specialized guidance while responsibility mentors oversee the training process, creating a collaborative education model characterized by “disciplinary integration, platform co-construction, and project co-research.” Implementation follows a “three-stage progressive” training pathway: ① Customizing personalized curriculum systems based on interdisciplinary research projects; ② Enhance innovation and practical skills through a dual-track system of “academic seminars and engineering training”; ③ Establish a dynamic evaluation mechanism to optimize training programs. This model integrates multidisciplinary resources to overcome challenges such as 分散 ed mentor attention and entrenched disciplinary barriers, achieving a closed-loop training cycle of “research demand-driven, iterative training programs, and innovation capability leap.” It provides institutional safeguards for cultivating interdisciplinary talent for the “dual carbon” goals.

4 Interdisciplinary collaborative training objectives

4.1 Clarify the multidisciplinary coupling mechanisms under the dual carbon strategy and establish a collaborative innovation system for interdisciplinary graduate education

Driven by the “dual carbon” strategy, there is an urgent need to establish a multidisciplinary collaborative innovation training system. This system centers on the three-dimensional integration of “knowledge-technology-industry”: in the knowledge dimension, establishing an interdisciplinary knowledge chain covering the entire carbon emission lifecycle; in the technology dimension, forming an innovation chain spanning “fundamental research-applied technology-commercialization”; and in the training dimension, creating a training paradigm based on “demand-driven, cross-disciplinary integration, and capability enhancement.” Specific implementation pathways include: developing modular interdisciplinary courses, assembling diverse mentor teams, constructing blended virtual-physical teaching platforms, and establishing dynamic evaluation mechanisms. This reform will effectively enhance graduate students' ability to solve complex problems, providing talent support for achieving the dual carbon goals.

4.2 Establish a graduate curriculum system oriented toward achieving carbon neutrality and carbon peaking goals, innovate the paradigm for cultivating scientific research capabilities in environmental engineering, and create a new mechanism for developing interdisciplinary talent through targeted cross-disciplinary training and multi-dimensional platform collaboration

The “dual carbon” oriented graduate curriculum system represents a key initiative in aligning educational innovation with national strategy. Guided by three-dimensional demands—technology, industry, and institutional frameworks—it constructs an “Environmental Engineering+ ” course matrix: the core layer focuses on carbon accounting and clean energy technologies; the expansion layer integrates AI and green finance modules; and the practice layer embeds CCUS R&D projects, forming a progressive training chain of “foundation-interdisciplinary-innovation.” Innovative training paradigms manifest as: ① The “Triple Mentor Synergy” mechanism (academic + industry + interdisciplinary mentors) addresses single-source guidance limitations; ② The “Virtual-Physical Integration” platform (virtual simulation + field diagnostics) strengthens practical capabilities; ③ The “Three-Stage Cultivation” pathway (research-competition-entrepreneurship) unleashes innovation potential. Through the synergy of knowledge integration, platform co-construction, and evaluation innovation, this approach ultimately builds a dynamic ecosystem for cultivating composite talents that dynamically matches “needs-resources-capabilities.” This ecosystem supplies industry leaders equipped with both technical expertise and systems thinking to advance the carbon neutrality strategy.

4.3 Advance the development of interdisciplinary mentor teams guided by the dual carbon goals, optimize faculty development mechanisms for cross-disciplinary fields, establish exemplary innovation platforms, and foster multidisciplinary collaborative innovation

Achieving the dual carbon goals requires deep integration across multiple disciplines. However, current university faculty teams are predominantly single-discipline oriented, making it difficult to meet the demands for cultivating interdisciplinary talent. Therefore, we should advance the development of cross-disciplinary faculty teams oriented toward the dual carbon goals, breaking down disciplinary barriers and integrating faculty resources from fields such as energy, environment, materials, and economics to form complementary research teams. Simultaneously, optimize faculty development mechanisms for interdisciplinary studies by enhancing teachers' cross-disciplinary collaboration capabilities through joint research projects and academic workshops. Building upon this foundation, establish exemplary innovation platforms—such as carbon-neutral joint laboratories or interdisciplinary research centers—to provide collaborative research vehicles for faculty and students. Ultimately, through institutional innovation and resource integration, drive deep multidisciplinary convergence in low-carbon technologies, carbon management policies, and related fields, thereby providing talent and intellectual support for the dual carbon strategy.

5 Specific methods for interdisciplinary collaborative training

Establish a three-pronged elite talent cultivation system centered on “demand orientation, interdisciplinary integration, and practice-driven empowerment”: ① Form an interdisciplinary mentor alliance implementing a dual-track guidance mechanism featuring “primary mentor responsibility + multidisciplinary collaboration”; ② Develop a “core modules + personalized customization” curriculum system, designing knowledge chains covering “carbon accounting-emission reduction technologies-policy design” based on major research projects; ③ Establish university-industry innovation platforms to achieve capability leaps from “academic cognition to technological R&D to engineering application” through tackling real-world challenges. This system breaks disciplinary barriers by integrating resources from environmental science, energy, economics, and other fields, forming a collaborative cultivation ecosystem of “disciplinary clusters-mentor teams-practical platforms.” It effectively addresses the fragmentation of knowledge and disconnect from practice inherent in traditional training, as illustrated in Figure 1.

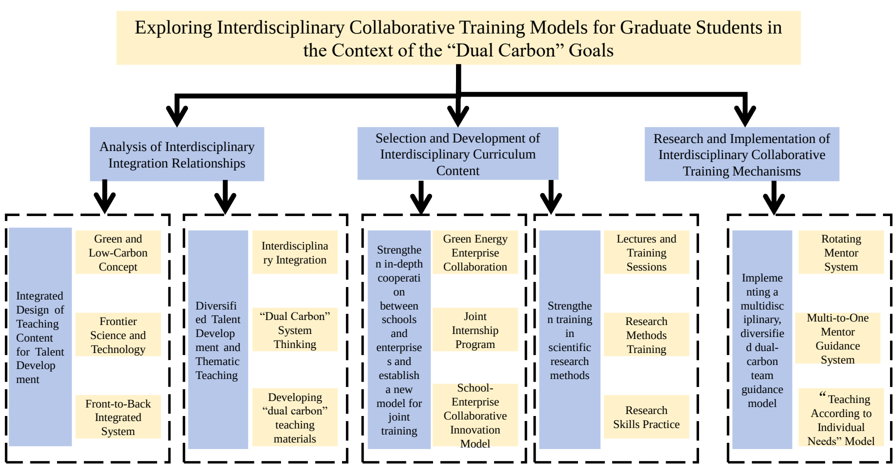

Figure 1 Proposed methodology roadmap

5.1 Integrate teaching content around “dual carbon” talent development, establishing a multidisciplinary, cross-disciplinary training model guided by scientific questions

This course closely tracks cutting-edge developments in the “dual carbon” field, innovatively integrating topics such as carbon detection, carbon footprint assessment, and carbon capture into the curriculum. It guides students to adopt a pollution control philosophy centered on “preventing pollution at the source while facilitating post-treatment, promoting green and low-carbon practices.” Employing a multidisciplinary training model, the program adopts a science-problem-oriented approach. It assembles teams of 4-6 mentors from diverse disciplines to conduct research projects leveraging existing scientific platforms. Graduate students may rotate through different research groups based on their study needs. This approach maximizes the utilization of teaching resources without requiring additional faculty or infrastructure costs, effectively enhancing innovative capabilities.

5.2 Strengthen multidisciplinary “thematic” teaching based on “dual carbon” talent development, and establish interdisciplinary mentor teams through collaborative platforms

Pollution control engineering under the dual-carbon framework integrates multidisciplinary knowledge spanning environmental science, energy, chemical engineering, and management, embodying a comprehensive blend of scientific theory, engineering technology, and policy management. Employing a thematic teaching approach centered on the core sequence of “carbon management—energy conservation and carbon reduction—carbon capture/storage/utilization,” it establishes a “theory-methodology-engineering” instructional model to systematically cultivate graduate students' capabilities in pollution control and low-carbon technology management. The training model employs a multidisciplinary faculty team system, where experts from different fields collaborate to provide guidance. The team jointly develops training plans and participates in key stages such as group meetings, thesis proposal reviews, mid-term evaluations, and thesis defenses, ensuring clear division of labor and efficient collaboration. Graduate students can rotate through different laboratories based on project requirements, receiving cross-disciplinary guidance to enhance their scientific research and innovation capabilities.

5.3 Implement a multidisciplinary, diversified “dual carbon” team guidance model and conduct multidimensional scientific research training

Pollution control engineering under the dual carbon goals spans multiple disciplines including environmental science, chemical engineering, mechanical engineering, and computer science. To this end, we have established a cross-departmental collaborative training mechanism. Through rotating guidance by multi-advisor teams, we have built a personalized “multiple-to-one” training system. This model integrates the strengths of various disciplines while cultivating students' innovative thinking and comprehensive capabilities. Throughout the training process, we emphasize three key aspects of research training: (1) systematic literature review; (2) interdisciplinary academic exchange; and (3) open-access experimental platforms. These training components aim to enhance students' theoretical literacy, innovative thinking, and practical skills, cultivating versatile talents capable of meeting the demands of the “dual carbon” goals.

5.4 Deepen School-Enterprise Collaboration And Establish New Joint Training Models, While Strengthening Research Methodology Training

Focusing on the national “dual carbon” strategy requirements, we will deepen the university-enterprise collaborative education mechanism. Through internship programs, joint training initiatives, and other models, we will cultivate versatile technical talents specializing in “dual carbon” technologies. We will advance interdisciplinary integration, establish a collaborative innovation system linking industry, academia, and research, and strengthen foundational research training for students. Systematic specialized training in literature retrieval, scientific writing, and instrument operation will be conducted to enhance graduate students' independent research capabilities, ensuring they can flexibly adjust research plans according to experimental needs.

6 Conclusion

Interdisciplinary research based on the dual carbon goals provides a theoretical foundation for establishing a composite graduate training system. Through cross-disciplinary training models and scientifically designed interdisciplinary curricula, we stimulate graduate students' academic potential while promoting the deep integration and practical application of multidisciplinary knowledge. Innovating the “dual carbon” talent cultivation model, we establish multidisciplinary “multiple-to-one” mentor teams to build an environmental engineering think tank. Through multidimensional collaboration both on and off campus, we integrate optimal teaching resources to stimulate graduate students' originality and comprehensively enhance their innovation literacy.

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