Reform Pathways and Future Prospects for Undergraduate Education in Coal Chemical Engineering under the New Engineering Paradigm

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Abstract

In response to the dual challenges posed by China's national "dual carbon" (carbon peaking and carbon neutrality) strategy and energy structure transformation, the coal chemical industry is rapidly evolving toward high-end, intelligent, and green development. Traditional educational models for cultivating coal chemical engineering talent have become increasingly inadequate in meeting the urgent demand for interdisciplinary, innovative engineers required by both the New Engineering initiative and industrial upgrading. Guided by the principles of New Engineering, this paper systematically analyzes the core challenges in current undergraduate education in coal chemical engineering and proposes a four-dimensional reform framework: industry-driven curriculum design, digital-technology-enabled pedagogy, engineering-competency-centered practice, and values-based education. By reconstructing course content, innovating blended teaching methodologies, building integrated virtual–physical practice platforms, and deepening the integration of ideological and political education into professional courses, this approach aims to cultivate high-caliber professionals equipped with solid theoretical foundations, exceptional engineering capabilities, sharp innovation awareness, and a strong sense of national mission. The paper further outlines future directions for coal chemical engineering education—toward greater intelligence, interdisciplinary integration, and ecological sustainability.

Keywords: New Engineering, Coal chemical engineering, Teaching reform, Industry–education integration, Digital education, Curriculum-based ideological and political education

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1. A New Educational Paradigm for Coal Chemical Engineering in the Era of New Engineering

China's energy endowment—characterized by abundant coal, scarce oil, and limited natural gas—ensures coal's role as a strategic "stabilizer" in national energy security [1]. Developing clean and efficient coal chemical technologies is thus a critical pathway to securing energy supply and diversifying feedstock sources for the chemical industry. With the advancement of the "dual carbon" goals and the deepening of the new industrial revolution, the coal chemical sector is undergoing a profound transition from scale-driven expansion to high-quality development centered on greenness, low-carbon operations, and intelligence. This transformation demands a fundamental rethinking of the knowledge structures, competencies, and innovative mindsets of future engineers.

The New Engineering initiative, a cornerstone of China's higher education reform strategy, seeks to proactively respond to the technological and industrial revolutions by fostering diverse, innovative, and world-class engineering talent. Within this context, traditional coal chemical engineering education faces significant challenges: curricula lag behind technological advancements; pedagogical methods remain largely didactic, stifling engineering thinking; practical training is weak and disconnected from real-world operations; and value-based education is often siloed from technical instruction. Consequently, a systemic reform grounded in New Engineering principles is urgently needed to establish a forward-looking talent development system aligned with future industrial and societal needs

2. Critical Challenges in Current Coal Chemical Engineering Education

2.1 Curriculum Misalignment with Industrial Frontiers.

Course content often remains anchored in legacy technologies such as conventional coking and fixed-bed gasification, with insufficient coverage or delayed updates on modern processes like coal-to-olefins (CTO), coal-to-ethylene glycol (CTEG), green hydrogen/ammonia integration, and carbon capture, utilization, and storage (CCUS) [2]. Textbooks rarely reflect the rapid technological shifts driven by the "dual carbon" agenda, resulting in a mismatch between graduate competencies and enterprise requirements.

2.2 Pedagogical Imbalance Between Knowledge Delivery and Competency Development.

Lecture-dominated instruction persists, offering students little opportunity for active exploration of complex process flows or equipment mechanics. Assessment emphasizes rote memorization over higher-order skills such as solving open-ended engineering problems, designing process systems, or optimizing integrated plants, thereby constraining the development of innovation and practical abilities.

2.3 Disconnect Between Practical Training and Real Engineering Practice.

Laboratory experiments and internships are often constrained by safety, cost, and logistical limitations, reducing them to observational exercises. Production internships frequently resemble "tourist visits," preventing deep engagement in operational decision-making or troubleshooting. Moreover, the weak linkage between theory and practice undermines the cultivation of engineering judgment, environmental responsibility, and teamwork.

2.4 Fragmentation Between Technical Instruction and Value Formation

Professional courses focus predominantly on technical knowledge, neglecting the organic integration of ideological and political elements such as national energy security, craftsmanship, scientific self-reliance, and sustainable development. As a result, students often lack a clear understanding of the strategic significance of their field, leading to insufficient professional identity and social responsibility.

3. Reform Pathways: A Four-Dimensional Integrated Talent Development Framework

To address these challenges, a holistic transformation of coal chemical engineering education is essential, centered on student outcomes and future readiness.

3.1 Industry-Driven Dynamic Curriculum Reconstruction.

Curricula must embrace "innovation through renewal." Outdated content (e.g., atmospheric fixed-bed gasification) should be streamlined, while modern modules—such as entrained-flow gasification, direct/indirect coal liquefaction, and methanol-to-olefins—should become core components. Emerging topics aligned with the "dual carbon" strategy—including green hydrogen coupling, CO_2 valorization, energy-efficient process integration, and intelligent control—must be incorporated [3]. Regional characteristics can further enrich relevance; for instance, Taiyuan University of Technology may integrate case studies on Shanxi's coal-based advanced materials and carbon products, ensuring curricula are both cutting-edge and locally grounded.

3.2 Digital-Enabled Blended Pedagogical Innovation.

Digital technologies should break temporal and spatial barriers in learning. Online platforms (MOOCs, SPOCs, virtual simulations) can deliver foundational knowledge, while face-to-face sessions focus on problem-solving, case discussions, and project presentations—realizing the flipped classroom model. Project- and case-based learning should be emphasized, using authentic scenarios (e.g., "Optimization of a 1-Mtpa Coal-to-Liquids Plant" or "Carbon Footprint Analysis of Coke Oven Gas-to-Hydrogen") to guide students through end-to-end engineering workflows. Modular virtual training systems—simulating tasks like gasifier startup or distillation column optimization—can provide safe, repeatable skill development.

3.3 Engineering-Centric Integrated Practice Platforms.

A progressive practice chain—from basic experiments and virtual simulations to course projects, internships, and capstone design—must be established. High-fidelity virtual–physical training centers, co-developed with industry leaders, can deploy operator training simulators (OTS) and digital twin systems, enabling students to safely practice full-plant operations, startups/shutdowns, and emergency responses [4]. Capstone and course design projects should draw directly from real industrial challenges, supervised by joint academic–industry mentors. Deepened industry–academia collaboration—through shared faculty appointments, teacher industry placements, and co-developed case libraries—ensures alignment between education and workforce needs.

3.4 Values-Based Integration of Ideological and Political Education.

Moral and civic education must be seamlessly woven into technical instruction. When teaching gasification or synthesis processes, instructors can contextualize content with narratives on national energy security (given high oil/gas import dependence), technological self-reliance (e.g., China's breakthroughs in indigenous coal-to-oil technology), engineering ethics, and green development pathways [5]. Complementary activities—such as site visits to national demonstration projects, guest lectures by industry pioneers, and debates on decarbonization strategies—can inspire students' sense of mission and professional pride, achieving unity among knowledge transmission, skill development, and value formation.

4. Future Outlook: Toward Intelligent, Integrated, and Ecological Education

Looking ahead, coal chemical engineering education will evolve along four trajectories:

Intelligent Educational Ecosystems: AI, big data, and extended reality (XR) will enable personalized learning paths, intelligent performance analytics, and immersive experiential environments, giving rise to "smart laboratories" and "future learning centers."

Interdisciplinary Convergence: Curricula will increasingly integrate chemical engineering with artificial intelligence, environmental science, materials science, and economics, cultivating leaders capable of managing complex socio-technical systems.

Lifelong Learning Architectures: Open, stackable course platforms with credit recognition mechanisms will support continuous upskilling for professionals, bridging formal education and workplace learning.

Ecological Talent Development Communities: Universities, research institutes, leading enterprises, and industry associations will form deeply collaborative "industry–education consortia," jointly setting standards, sharing resources, and aligning education, talent, industrial, and innovation chains.

5. Conclusion

Reforming coal chemical engineering education under the New Engineering paradigm represents a profound transformation in educational philosophy, content, methodology, and assessment. It demands a strategic shift—away from path dependency and toward student-centered, innovation-focused development that leverages digital tools and deeply integrates industrial resources, all while embedding value formation throughout the learning journey. Through systematic reform and sustained practice, this approach will cultivate a new generation of outstanding engineers: technically rigorous, practically adept, creatively driven, and nationally committed—providing robust human capital and intellectual support for the high-quality development and energy security of China's chemical and energy sectors.

Moreover, this reform is not merely an institutional adjustment but a cultural evolution—one that redefines the engineer's role from a technical executor to a responsible innovator and societal steward. In an era where energy transitions intersect with technological disruption and global climate imperatives, the reimagined coal chemical engineering education must serve as both a crucible for technical excellence and a compass for ethical leadership. Only then can it fulfill its mission: nurturing talents who not only master the molecules and reactors of today but also shape the sustainable energy systems of tomorrow.

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