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Research on Reform Pathways for China's Higher Engineering Education to Meet Future Industrial Demands

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Abstract:

Against the backdrop of accelerating global industrial transformation and the continuous emergence of future industries, China's higher engineering education system faces unprecedented challenges and opportunities. To meet the forward-looking demands of future industries—such as the metaverse, quantum information, artificial intelligence, and biomanufacturing—on the competency structure of engineering talent, advancing systematic reforms in engineering education has become a critical pathway to enhance national innovation capacity and industrial competitiveness. This study is grounded in the practical context of China's engineering education, focusing on core elements such as curriculum systems, teaching methods, faculty structures, and practical training mechanisms. It systematically explores pathways for aligning these elements with the demands of future industries. Employing multiple research methodologies, the study first conducts a systematic literature review to trace the theoretical evolution and practical experiences of engineering education reform globally. Building upon this foundation, it utilizes multi-case studies to deeply analyze the reform logic and implementation mechanisms of exemplary cases, including Chinese engineering institutions and MIT's NEET program. Concurrently, semi-structured interviews are conducted with four key groups—university faculty, corporate technical leaders, engineering students, and education policymakers—to gather firsthand data on competency demands and educational realities. Finally, comparative research methods were employed to evaluate the applicability and outcomes of different reform pathways, distilling transferable insights tailored to the Chinese context. This study aims to identify structural gaps between the current higher engineering education system and future industrial demands, explore feasible and scalable engineering education reform pathways with Chinese characteristics, and provide theoretical foundations and practical references for building a future-oriented higher engineering education system.

Keywords: Higher Engineering Education; Future Industries; Reform Pathways; Industry-Education Integration

1. Research Background and Problem Statement

Future industries are forward-looking emerging sectors driven by cutting-edge technologies, characterized by strategic importance, leadership, disruptive potential, and uncertainty [1]. Currently, the world is undergoing a new round of technological revolution and industrial transformation driven by cutting-edge technologies such as artificial intelligence, biotechnology, and new energy. This global industrial transformation has not only given rise to an entirely new industrial ecosystem but has also fundamentally reshaped the demands for the knowledge, competencies, and qualities of engineering talent. Against this backdrop, higher engineering education—as the primary channel for cultivating outstanding engineering talent for the nation—faces unprecedented challenges in adapting to these changes.

Therefore, this study aims to address a core issue of both national strategic significance and global relevance: given the accelerating evolution of global industries toward future forms, how should China's higher engineering education establish a new talent development system that dynamically adapts to future industrial needs through systematic and forward-looking reforms? First, regarding the identification of needs: What are the specific core competency requirements that future industries place on engineering talent? What are the key gaps between these requirements and the current outputs of engineering education? Second, regarding the diagnosis of the current situation: What contradictions exist within China's current higher engineering education system—in core elements such as curriculum, teaching, faculty, practical training, and evaluation—that render it incompatible with future demands? Furthermore, regarding pathway design, on what concepts and principles should the reform path for China's higher engineering education be restructured? Finally, regarding the adoption of international experiences, what transferable insights and lessons can cutting-edge international engineering education reform practices offer China, and how can the "rejection reaction" encountered during the localization process be overcome?

2. Literature Review

Future industries are new industrial forms driven by disruptive technologies and cutting-edge science, characterized by high growth potential, strategic importance, and uncertainty [2]. Their development relies not only on technological breakthroughs but also urgently requires engineering talent capable of adapting to and leading such transformations. It is widely acknowledged in academia that future industries demand a systematic reshaping of the competency structure of engineering talent, moving beyond an emphasis on single technical skills toward a call for versatile, innovative professionals with high adaptability and a strong sense of responsibility [3].

Facing the challenges of future industries, global higher engineering education is undergoing a profound paradigm shift. Its evolutionary trajectory reflects a transition from a scientific paradigm focused on the transmission of fundamental scientific knowledge, to an engineering paradigm emphasizing engineering practice and system integration, and further toward an innovation paradigm—or future paradigm—centered on addressing future uncertainties and cultivating innovation and entrepreneurship capabilities [4]. Against this backdrop of macro-level paradigm shifts, China's higher engineering education reforms resonate in sync with the evolution of national industrial strategies. Since the launch of the "New Engineering" initiative under the "Fudan Consensus" in 2017, engineering education has entered a new phase of systematic reform aimed at proactively shaping the future and cultivating innovative talent [5]. From the "Tianjin University Initiative" to the "Beijing Guidelines," the Ministry of Education has established new organizational models—such as Future Technology Colleges, Modern Industry Colleges, and Colleges of Excellence in Engineering—aiming to break down disciplinary barriers, deepen industry-education integration, and explore a Chinese solution for engineering education reform [6]. These initiatives provide a clear top-level design for reform, emphasizing the organic integration of the education chain, talent chain, industrial chain, and innovation chain.

Although China's higher engineering education has achieved significant progress and innovation, numerous studies indicate that a gap still exists between the current engineering education system and future industrial demands [7]. First, the pace of updating engineering knowledge lags far behind the exponential iteration of industrial technologies, resulting in a severe disconnect between teaching content and industry frontiers [8]. Second, university-industry collaboration mostly remains at a superficial level—such as internship bases, equipment donations, and expert lectures—making it difficult for enterprises to deeply engage in the entire talent cultivation process [9]. Finally, the evaluation systems for university faculty generally prioritize research output, resulting in a lack of first-hand industry experience among instructors and making it difficult for them to effectively guide students in solving complex engineering problems [10].

In response to these challenges, Chinese academia and the professional community have engaged in in-depth discussions regarding reform pathways. Regarding the deepening of industry-education integration, the research consensus holds that it is essential to move beyond simple collaboration and establish long-term partnerships and an institutionalized ecosystem for collaborative talent development [11]. The theory of integrating the "industrial chain, innovation chain, capital chain, and talent chain" provides an analytical framework for systematically constructing mechanisms for industry-education integration [12]. Regarding the promotion of interdisciplinary education, research has focused on how to break down entrenched barriers between schools, departments, and disciplines. This requires not only the establishment of interdisciplinary majors or micro-majors such as "Artificial Intelligence + X," but also profound organizational and institutional innovation [13]. Regarding the reform of engineering education evaluation, establishing a diverse, dynamic, and competency-based evaluation system is viewed as the key to reform [14]. In terms of technology-enabled educational transformation, technologies such as artificial intelligence, big data, and digital twins are reshaping engineering education scenarios; however, the application of these technologies must be deeply integrated with the objectives of engineering education to avoid becoming merely a formalistic substitution of tools [14].

Leading engineering schools and consortia around the world have embarked on distinctive and systematic reform initiatives. The Massachusetts Institute of Technology's "New Engineering Education Transformation (NEET) Initiative" serves as a model of systematic restructuring; its core lies in thoroughly breaking down traditional departmental and curricular barriers, using in-depth projects spanning the entire undergraduate program as a vehicle to cultivate students' ability to address complex global challenges [12]. The European Alliance for Innovation and Science in Engineering Education (EELISA) initiative aims to deeply integrate sustainability, social ethics, and European values into the entire engineering education process, fostering engineering leaders with a strong sense of social responsibility [15]. Additionally, Singapore's nationwide skills reskilling initiative, designed to align with the digital economy, demonstrates a high degree of synergy between national strategy and engineering education reform [8].

Existing research has clearly revealed the disruptive nature of future industries and the urgency of reshaping the competency structure of engineering talent; it has systematically mapped out the global trend toward a transformative paradigm in engineering education characterized by interdisciplinarity, project-based learning, and deep integration of industry and education;It has also conducted an in-depth analysis of the structural bottlenecks encountered in China's reform practices—represented by the "New Engineering" initiative—in areas such as curriculum, faculty, industry-education integration, and evaluation; and has explored key pathways such as deepening industry-education integration, interdisciplinary training, evaluation reform, and technology empowerment from multiple perspectives.

However, significant gaps remain in existing research. First, there is a lack of foresight in responding to demand. Most studies offer only generalized analyses of the dynamic and differentiated talent needs of future industries. Second, research on adapting international experiences to the local context is weak; there is insufficient exploration of how such experiences can be adapted to China's unique higher education management system, cultural background, and industrial ecosystem, including their implementation mechanisms and potential conflicts. Third, there is a lack of synergy and systematic design in reform pathways. Research has largely focused on isolated breakthroughs in single elements such as curriculum, practical training, or faculty, lacking a systematic framework that treats multiple elements—including curriculum, teaching methods, faculty, and evaluation—as an organic whole to explore their synergistic evolution and interconnected reform. Finally, there is a scarcity of empirical evidence grounded in a multi-stakeholder perspective. Reform recommendations often stem from theoretical extrapolation or the perspective of administrators, lacking in-depth empirical investigations that simultaneously integrate the multidimensional perspectives of university faculty, students, corporate technical managers, and education policymakers.

3. Research Design

This study follows a closed-loop logic of "problem diagnosis—needs analysis—pathway construction—case validation—proposal of countermeasures." First, through literature review, we clarify the theoretical framework and practical experience of engineering education reform both domestically and internationally; through textual analysis, we systematically organize relevant policy documents to establish the theoretical foundation and cutting-edge understanding of the research;Second, semi-structured interviews are conducted with four categories of key stakeholders to identify the gap between future industry competency requirements and current engineering education, thereby constructing a reform pathway for higher engineering education that aligns with future industry needs; Finally, through comparative case studies and reflection, the reform pathways and implementation outcomes of universities in different countries and of different types are compared, and suitable solutions for the Chinese context are explored through an analysis of these differences.

4. Future Industry Talent Needs and the Current State of Engineering Education

4.1 Characteristics of Future Industries and Core Competency Requirements for Engineering Talent

To precisely define the direction of higher engineering education reform, it is essential to systematically clarify the core characteristics of future industries and their competency requirements for talent. This study comprehensively employs policy text analysis and in-depth interviews to distill three major characteristics of future industries from the dual perspectives of national strategic planning and frontline industrial needs, and constructs a core competency model for future engineering talent comprising six competency dimensions.

(1) Selection and Analysis of Policy Documents

Using keywords such as "future industries," "engineering talent," "engineer training," and "educational reform," this study retrieved and screened six representative and complementary policy documents issued by national-level ministries and commissions. Subsequently, content analysis was employed to extract key statements regarding the development direction of future industries, technological characteristics, competency requirements for talent, and pathways for training reform.

Table 1: Basic Information on Policy Documents

Document Title	Date of Issuance	Focus of Policy Text
"Guiding Opinions on Deepening the Reform of the Professional Title System for Engineering and Technical Personnel"	2019	The State's Official Definition of Core Competencies for Engineering and Technical Personnel
"Implementation Plan for the Professional Technical Personnel Knowledge Update Project"	2021	A lifelong learning and competency renewal system for technical professionals in major national strategic and cutting-edge fields, supporting the continuous evolution of talent capabilities
"Implementation Opinions on Strengthening and Improving the Development of the Industrial and Information Technology Talent Pool"	2022	A holistic talent strategy and framework for workforce development aimed at building a manufacturing powerhouse and a cyber powerhouse
"Implementation Opinions on Promoting the Innovative Development of Future Industries"	2024	Definition, Key Directions, and Technological Pathways of Future Industries; Understanding Industry Characteristics

"Opinions on Strengthening the Development of Data-Related Academic Disciplines and the Construction of Digital Talent Teams"	2025	New Requirements for Talent Capabilities, Particularly Digital Literacy, in the Era of Data as a Factor of Production
"Standards for the Accreditation of Excellence in Engineering Education"	2025	Quality Dimensions and Core Requirements for the Training of Outstanding Engineers: Bridging Industry Needs and Educational Practice

(2) Interview Design and Implementation Process

To gain firsthand insights from industry practice, the study designed and conducted semi-structured interviews with corporate technology executives. The selection of interviewees followed the principle of purposive sampling to ensure coverage across multiple future industry sectors, with all participants holding key positions on the front lines of R&D or technology management. The interview outline was designed around three main themes: "Corporate Perceptions of Future Industrial Transformation," "Current Status of Engineering Talent Development," and "Specific Recommendations for University Engineering Education." Each interview lasted 60–90 minutes.

Table 2: Basic Information on the Sample of Corporate Technical Managers Interviewed

No.	Company Type	Position	Core Business or Field
P-01	Intelligent Connected Vehicle Company	Director of Intelligent Driving Systems R&D	High-Level Autonomous Driving, Vehicle-Road-Cloud Integration
P-02	New Energy Battery Company	Director of the Advanced Materials Laboratory	Solid-State Batteries, Next-Generation Energy Storage Materials
P-03	Industrial Internet Platform Company	Chief Architect	Industrial Internet Platform, Digital Twin Solutions
P-04	Humanoid Robot Startup	Co-founder and CTO	Research and Development of General-Purpose Humanoid Robots
P-05	Biomanufacturing Company	Director of Synthetic Biology R&D	Synthetic Biotechnology, Cell Factories
P-06	Smart Energy Solutions Provider	General Manager of the Smart Energy Division	Integrated Energy Systems, Virtual Power Plants
P-07	Leading Consumer Electronics Company	Chief Scientist, Human-Computer Interaction Laboratory	Next-Generation Smart Devices, Brain-Computer Interfaces

(3) Characteristics of Future Industries and Core Competency Requirements for Engineering Talent

Through a systematic analysis of national policy documents and in-depth interviews with industry technology leaders, this study has identified three core characteristics of future industries: “digital intelligence, convergence, and innovation.”

(a) Digital intelligence serves as the cornerstone and core driving force of future industrial development. It has evolved from a mere technological application to a foundational logic that defines industrial forms and drives innovation across the entire value chain. Policies explicitly state that future industries are driven by cutting-edge technologies, with development priorities including artificial intelligence, advanced computing, swarm intelligence, and large-scale models, while positioning data as the key to unlocking new productive forces. “Digital twins are not merely about visualization; they involve real-time mapping and intelligent optimization of physical systems within a virtual space, underpinned by the integration of massive data and AI models.” (P-03)

(b) Convergence-driven development is the primary path and organizational paradigm for the evolution of future industries. Future industries are increasingly emerging at the intersection of disciplines and technologies, and systemic breakthroughs depend on deep cross-disciplinary collaboration [16]. National policies emphasize cross-disciplinary technological convergence and innovation, and are committed to building an ecosystem where innovation chains, industrial chains, capital chains, and talent chains are deeply integrated. “Next-generation smart devices involve neuroscience, signal processing, hardware design, user experience, and many other aspects; we must break down disciplinary barriers.” (P-07)

(c) Innovation is the soul and fundamental attribute of future industries; the essence of competition in future industries lies in the speed and depth of original innovation. Policy documents define future industries as emerging sectors characterized by significant strategic importance, leadership, disruptive potential, and uncertainty, with their development driven by original and disruptive technological innovation [17]. “From motor drive to whole-body coordinated control, every step is uncharted territory. Innovation is not merely about technological breakthroughs; it also involves the creative definition of application scenarios.” (P-04)

Based on the identification of the three key characteristics of future industries, this study further constructs a core competency model for future engineering talent comprising six capability dimensions.

(a) The ability to gain insights into and apply cutting-edge technologies is the foundation for responding to rapid industrial iteration. Policy requirements stipulate that engineers must be capable of keeping abreast of the latest scientific and technological developments in their fields and engaging in the research and development of disruptive technologies. “Engineers cannot merely understand existing technologies; they must continuously track cutting-edge advancements and even participate in defining future technology roadmaps.” (P-06)

(b) The ability to solve complex systems is key to mastering the converged industrial ecosystem. At the policy level, "leading and building major engineering projects, and being able to solve complex engineering problems" is identified as a core standard for senior engineering and technical talent. "Autonomous driving is a typical complex systems problem—involving hardware-software coupling, human-machine co-driving, and ethical decision-making—which must be coordinated at the system level." (P-01)

(c) Interdisciplinary collaboration is the practical guarantee for translating convergence into innovative outcomes. Policies explicitly call for cultivating high-level, multidisciplinary talent with the potential to become strategic scientists. "Our team includes biologists, programmers, and mechanical engineers; only by truly understanding each other's language can we drive the project forward." (P-05)

(d) Digital literacy has become a foundational, universal competency and a new professional threshold for engineering talent. The state has institutionalized and systematized the Digital Technology Engineer training program, stipulating that its certification may serve as an important reference for professional title evaluations [18]. The industry regards it as essential: "In the future, Python may become as fundamental as CAD." (P-03)

(e) Innovation and entrepreneurial spirit are the intrinsic engines driving disruptive breakthroughs. The policy focuses on optimizing an innovation and entrepreneurship environment that encourages originality and tolerates failure."Without a strong intrinsic drive and a spirit of adventure, it is difficult to see disruptive innovation through to the end." (P-02)

(f) Engineering ethics and a commitment to sustainable development are the value cornerstones ensuring the healthy development of the industry. Policies emphasize the coordinated management of technological innovation and ethical governance, establishing ethical red lines. "Should robots possess emotions? How can we avoid algorithmic bias? These ethical issues must be incorporated into the design process from the very beginning." (P-04)

Table 3: Frequency and Weight Analysis of Interview Mentions for the Six Core Competencies

Competency Dimension	Frequency of Mention	Proportion Highlighted as "Core Competency"
Insight into and Application of Cutting-Edge Technologies	43 times	76.5%
Complex system problem-solving capabilities	51 times	88.2%
Interdisciplinary Collaboration Skills	38 times	70.6%
Digital literacy	47 times	82.4%
Innovation and Entrepreneurship	29 times	58.8%
Engineering Ethics and Sustainability	24 times	41.2%

Note: "Emphasized as a core competency" refers to the proportion of respondents who selected a particular competency when asked, “Which three competencies do you consider most important?”

Table 4: Quantitative Analysis of the Correlation Between the Three Major Characteristics and the Six Core Competencies

Competency Dimension	Co-occurrence Frequency with “Digital Intelligence”	Co-occurrence Frequency with “Convergence”	Co-occurrence Frequency with “Innovation”	Key Associated Characteristics
Cutting-Edge Technology Insights and Application Capabilities	31 times	18 times	43 times	Innovation
Complex System Problem-Solving Skills	38 times	42 times	29 times	Integration
Interdisciplinary Collaboration Skills	22 times	51 times	26 times	Integration
Digital literacy	59 times	27 times	21 times	Digital Intelligence
Innovation and Entrepreneurship	19 times	16 times	48 times	Innovation
Engineering Ethics and Sustainable Development	18 times	21 times	14 times	Convergence or Digital Intelligence

Note: Co-occurrence analysis is based on the frequency of feature words and competency words appearing within the same paragraph in the interview transcripts.

4.2 Diagnosis of the Current State and Structural Contradictions in China’s Higher Engineering Education

To diagnose the structural contradictions and alignment between China’s higher engineering education and future industrial demands, the study conducted semi-structured interviews with engineering faculty and engineering students at universities, aiming to capture stakeholders’ firsthand perceptions of the current educational landscape. The interview outline was designed around four key dimensions—curriculum, teaching, faculty, and practical training—focusing on their current status, challenges, and perceived gaps relative to industrial needs. The interviews were conducted using a combination of online and in-person methods, with each session lasting approximately 60–90 minutes.

The interviewees represent both the undergraduate and graduate levels of higher engineering education in China. The student sample includes undergraduates, master’s students, and doctoral students, while the faculty sample consists of instructors who teach undergraduate courses and supervise graduate students. At the undergraduate level, the focus is on the curriculum design, teaching methods, practical training, and competency attainment in engineering disciplines; at the master's level, the focus is on training models and mechanisms for industry-education integration; and at the doctoral level, the focus is on the development of cutting-edge research capabilities, as well as the industry-oriented problem-solving approach of engineering doctoral programs.

This study systematically examines both the undergraduate and graduate stages of China's higher engineering education, viewing them as an interconnected and indivisible continuum of talent development. The decision to examine both stages simultaneously is primarily based on the following considerations. First, the progressive and complementary nature of educational objectives. The undergraduate stage emphasizes consolidating disciplinary foundations, cultivating systematic thinking and engineering literacy, and establishing a broad knowledge base for students; the graduate stage, in contrast, focuses on the in-depth development of capabilities for exploring cutting-edge fields, tackling complex problems, and achieving original innovation. Second, the continuity and synergy of reform pathways. Reform initiatives such as curriculum restructuring, innovation in teaching methods, and deep integration of industry and education require organic coordination between the undergraduate and graduate stages. Therefore, this study incorporates both stages into its analytical framework as a unified whole, examining not only the unique patterns and reform priorities of each stage but also the mechanisms of transition and pathways for synergy between them, with the aim of providing a comprehensive reference framework for the systematic reform of China's higher engineering education.

Table 5: Basic Information on Faculty and Student Interview Samples

No.	Title/Position/ Educational Level	Type of Institution	Field of Study
T-01	Associate Professor	"Double First-Class" Initiative University	Control Science and Engineering
T-02	Lecturer	Provincial Key University of Science and Technology	Electronic Science and Technology
T-03	Associate Professor	"Double First-Class" Initiative University	Computer Science and Technology
T-04	Associate Professor (Dual-Qualified)	Provincial Key University of Science and Technology	Telecommunications Engineering
T-05	Professor/Vice Dean	Industry-oriented University	Mechanical Engineering
S-06	Senior Undergraduate	"Double First-Class" Initiative University	Mechanical Design, Manufacturing, and Automation
S-07	Fourth-year Undergraduate	Industry-oriented University	Electronic and Information Engineering

S-08	Doctoral Student	“Double First-Class” Initiative University	Biomedical Engineering
S-09	Master’s Degree	Provincial Key University of Science and Technology	Software Engineering
S-10	Master’s Degree	“Double First-Class” Initiative University	Power Engineering and Engineering Thermophysics

Based on a quantitative coding analysis of interview data, this study identifies systemic contradictions in China’s higher engineering education across four core dimensions. These contradictions have led to a mismatch between talent cultivation and future industrial needs.

Table 6: Frequency and Proportion of Interview Mentions Regarding Structural Contradictions

Dimension	Coding Indicators (Question Categories)	Frequency of Mentions (Number of Respondents)	Proportion of Mentions (%)
Curriculum System	Curriculum content lags behind industrial technological development	10	100
	Insufficient offerings of cutting-edge or interdisciplinary courses	9	90
	Barriers to cross-departmental course selection or credit transfer	6	60
Teaching Methods	Classes are primarily lecture-based, with insufficient interaction	10	100
	Project-based learning is superficial and lacks real-world problems	8	80
	Assessment methods are limited, and formative assessment is lacking	7	70
Faculty	Teachers lack practical engineering experience	9	90
	Faculty evaluations prioritize research over engineering practice	8	80
	Faculty lack sufficient understanding of cutting-edge industry trends	7	70
Practical Training	Internships are limited to observation or auxiliary tasks	9	90
	Industry-academia collaboration projects are difficult to integrate into the curriculum or graduation projects	7	70
	Lack of opportunities to engage with real-world industry challenges	8	80

Note: Frequency of mention refers to the cumulative number of respondents who explicitly mentioned the issue among 10 respondents; a single respondent may have mentioned multiple issues.

First, the curriculum system exhibits distinct characteristics of rigidity and lag, making it difficult to respond quickly to trends in technological iteration and industrial development. The process for revising course syllabi is cumbersome, often taking several years, resulting in slow curriculum updates. “Core course textbooks still focus heavily on architectures from ten years ago.” (T-03) There is an insufficient supply of content in cutting-edge and interdisciplinary fields; classroom instruction primarily focuses on classical theories, with coverage of cutting-edge areas limited to the introduction of terminology. “I know our major will inevitably integrate with artificial intelligence in the future, but there are no systematic courses to teach me how to do so.” (S-08) Disciplinary barriers hinder knowledge integration. Obstacles exist between departments regarding course selection and credit recognition, making it difficult for students to independently build interdisciplinary knowledge systems based on personal interests or developmental needs. S-06 shared that they wanted to work on intelligent robots, which requires knowledge of automation and computer science, but encountered issues such as full enrollment and incomplete credit recognition when selecting courses, ultimately forcing them to self-study through online courses.

Second, classroom instruction remains dominated by one-way knowledge transmission, marginalizing the cultivation of students’ higher-order thinking and complex problem-solving skills. The norm in the classroom is teachers lecturing, students taking notes, and cramming before exams. “We know we need to develop design and debugging skills, but most of the class time is spent deriving formulas and memorizing principles.” (S-07) Project-based learning is often superficial and lacks challenge; although some courses incorporate design projects, they are disconnected from real-world engineering problems.“Many course design projects have idealized parameters and singular objectives, lacking the ambiguity, conflicting constraints, and iterative optimization processes found in industrial R&D.” (T-02) Undergraduates face even greater challenges than graduate students when participating in interdisciplinary, project-based learning; “knowledge gaps that lag behind project requirements” constitute the core obstacle to undergraduates undertaking such projects.“Interdisciplinary projects require us to master diverse knowledge, but our curriculum is linear. In lower-level years, we can only take foundational courses in our major and have no opportunity to engage with content from other disciplines. By the time we reach upper-level years and have sufficient knowledge, we face the pressure of preparing for graduate school entrance exams or job hunting, making it difficult to sustain commitment to a single project for more than two years.” (S-06)

Third, there is a contradiction between the academic orientation of the faculty and the practical nature of engineering education. Recruitment and evaluation systems prioritize research over engineering. In university talent recruitment and promotion, publications and grant projects are considered hard currency, while engineering practical experience and technology transfer achievements are often given very low weight. “My strength lies in technology implementation, but during evaluations, these are far less effective than publishing a paper in a top-tier SCI journal." (T-04) Faculty members themselves have weak engineering backgrounds; many have never worked in industry, having moved directly from one academic institution to another. "When I teach control system design, most of my case studies come from textbook simulations or research papers, but since I haven't built them myself, I can't explain them in depth or make them come alive." (T-01) This makes it difficult to bridge the gap between theoretical knowledge and engineering practice in teaching. Furthermore, within the context of China's large-scale engineering education system, balancing scale and quality is a challenge that must be addressed head-on. "Successful talent development programs strictly limit the number of students admitted each year per specialization, because high-quality mentoring requires an extremely low student-to-faculty ratio and personalized support." (T-03)

Fourth, practical instruction is viewed as a key bottleneck and pain point in reform, as universities and enterprises have failed to form a deeply integrated educational community. Collaboration remains limited to observational internships and short-term training programs; the internship positions provided by companies are mostly observational or auxiliary in nature, making it difficult for students to engage with technical processes and real-world problems. "Summer internships consist of running tests and organizing documents—it's like doing menial tasks." (S-09) Real-world industry projects are difficult to systematically integrate into the curriculum and graduation projects. "Projects provided by enterprises for teaching purposes either have cycles that are too long to fit the academic schedule or involve trade secrets. In the end, what students are often given to work on are leftover problems or old, already-published problems." (T-05) This results in a disconnect between key practical components and industry frontiers, leading to a lack of innovation.

4.3 Analysis of the Gap Between Demands and Current Reality

Based on a systematic comparison of future industry core competency requirements and the current state of higher engineering education, the study found significant gaps between the two across multiple dimensions. First, teaching content fails to respond adequately to cutting-edge technological trends, leaving students with only a conceptual understanding of emerging fields; teaching is fragmented and lacks realistic simulations of complex system problems, resulting in weak systematic thinking and global optimization capabilities among students. Second, there is a disconnect between the cultivation of complex system problem-solving skills and teaching practices. Existing instruction often breaks down knowledge into isolated course modules, leaving students ill-equipped to tackle open-ended, ill-defined problems. Third, interdisciplinary collaboration mechanisms are lacking; rigid disciplinary barriers prevent students from gaining authentic experience in collaborative integration within multidisciplinary teams. Fourth, the development of digital literacy lags behind; courses lack systematic integration of cutting-edge technologies such as artificial intelligence and big data. Faculty members exhibit significant gaps in digital competencies, making it difficult for students to master the core capabilities required for data- and algorithm-driven engineering innovation. Fifth, regarding the cultivation of innovative abilities, current education lacks the cultural and institutional support needed to encourage exploration and tolerate failure, resulting in students' insufficient insight into cutting-edge developments. Sixth, the cultivation of engineering ethics and sustainable development perspectives has not been deeply integrated into professional instruction; teaching often remains superficial and fails to guide students in internalizing ethical trade-offs and social responsibility within the innovation process. Overall, current engineering education exhibits a systemic misalignment with future industrial demands in areas such as the innovation ecosystem, cross-disciplinary collaboration, renewal mechanisms, systematic teaching, and value-driven leadership. This gap urgently requires bridging through a comprehensive restructuring of curricula, teaching methods, faculty development, and evaluation systems.

5. Systematic Construction of Reform Pathways for Engineering Education Oriented Toward Future Industries

To achieve dynamic alignment between talent development and industrial advancement, it is essential to design a forward-looking and systematic reform pathway. This study aims to construct a comprehensive reform plan guided by advanced concepts, covering core training elements, and equipped with solid support and momentum, thereby providing a clear and actionable framework for the transformation and upgrading of China's higher engineering education.

5.1 Reform Philosophy and Principles

To address the fundamental challenges posed by the digitalization, convergence, and innovative development of future industries, higher engineering education reform must establish a new overarching philosophy. This study proposes the "ACE" reform philosophy, centered on Anticipatory, Convergent, and Ecological principles. Anticipatory emphasizes that education should shift from passive adaptation to active shaping, proactively planning the direction and content of talent development; Convergent aims to break down barriers between disciplines, academia and industry, technology and the humanities, promoting the cross-pollination and integration of knowledge, resources, and stakeholders to build an integrated education model; Ecological views engineering education as an open, collaborative, and evolving complex system, dedicated to constructing a sustainable ecosystem of value co-creation and positive interaction among multiple stakeholders, including government, universities, enterprises, and society.

Guided by these principles, reform practices must adhere to four core tenets. First is the principle of balancing foresight and adaptability: the curriculum must incorporate cutting-edge technology modules while maintaining flexibility through dynamic adjustment mechanisms to address the uncertainties of industrial development. Second is the principle of deep industry-education integration, which fosters a substantive partnership between universities and enterprises throughout the entire talent development process, characterized by "joint planning, joint teaching, joint evaluation, and shared benefits." Third is the student-centered principle, whereby all instructional design and evaluation should aim to align students' competency development with future industry demands. Fourth is the principle of interdisciplinary integration and systems thinking, which ensures, through institutional design, that students can integrate multidisciplinary knowledge and develop their capacity for holistic thinking [19].

5.2 Design of the Reform Pathway

The establishment of reform concepts and principles has charted a course for concrete action, while the implementation of these concepts ultimately depends on the restructuring of key stages in talent development. Based on the five core dimensions of curriculum, teaching, faculty, practice, and evaluation, we propose an integrated reform pathway characterized by interconnectedness and synergistic advancement to resolve deep-seated contradictions within the engineering education system and achieve a precise response to future industry demands.

Path 1: Reconstruction of the Curriculum System—Transitioning from Rigid and Lagging to Dynamic and Modular

(a) Establish cutting-edge technology modules: Offer introductory and specialized courses in fields such as artificial intelligence and quantum information, and implement a mechanism for regular content review and updates every 1–2 years;

(b) Strengthen Core Engineering Foundation Modules: Optimize foundational courses in mathematics, physics, and engineering, and enhance their relevance to cutting-edge application scenarios;

(c) Add cross-disciplinary integration modules: Incorporate courses on design thinking, engineering ethics, and sustainable development to cultivate students' interdisciplinary perspectives and sense of social responsibility;

(d) Developing a Project-Based Curriculum Chain: Designing multidisciplinary integrated projects that progress in complexity from lower to upper class levels.

Pathway 2: Innovation in Teaching Methods—Transitioning from Knowledge Transmission to Competency Development

(a) Comprehensively implement a real-project-based teaching model: Collaborate with enterprises to develop authentic industry-based projects, enabling students to integrate knowledge and hone skills while solving practical problems;

(b) Deeply integrate virtual simulation and digital twin technologies: Build high-fidelity virtual experimental environments, enabling students to simulate, analyze, and optimize complex systems under safe and cost-effective conditions;

(c) Strictly implement outcomes-based process management: Set clear competency objectives for each project phase and use detailed evaluation rubrics to provide continuous formative assessment and feedback on students' systems thinking, iterative innovation, and team collaboration [20].

Path 3: Faculty Optimization—Overcoming the Bottleneck of Insufficient Engineering Practice Experience

(a) Implementing an Industry Professor Appointment System: Establishing a dedicated pathway to attract top technical experts from the industry to serve as full-time or part-time professors, leading project supervision;

(b) Establish a routine corporate rotation system for young faculty: Require young engineering faculty to regularly undertake engineering practice at partner companies, making this a prerequisite for promotion;

(c) Build interdisciplinary teaching communities: Centered around comprehensive project-based courses, form teaching teams composed of faculty from different departments and industry mentors. Through collaborative design and guidance, promote faculty knowledge renewal and enhance interdisciplinary teaching capabilities.

Pathway 4: Co-building a Practical Ecosystem—Evolving from Superficial Internships to In-Depth Innovation

(a) Co-establish Future Industry Innovation Laboratories: Universities and enterprises will jointly invest resources to build collaborative R&D and talent development platforms focused on cutting-edge fields, making them core bases for students to conduct high-level graduation projects and research training;

(b) Operating a Pool of University-Industry Collaborative Education Projects: Student teams tackle real-world problems under the guidance of dual mentors. Supporting mechanisms for credit recognition and the commercialization of outcomes are established to ensure that students' in-depth practical experiences are formally recognized toward their academic requirements;

(c) Establishing an Incubation Channel for Innovative Outcomes: Providing incubation support—such as seed funding and entrepreneurial guidance—for outstanding innovative outcomes emerging from projects to accelerate their transition from the laboratory to the market.

Pathway 5: Evaluation and Quality Assurance—Establishing a Future-Oriented, Multi-Stakeholder Evaluation System

(a) Incorporate in-depth participation by third-party industry experts in talent evaluation: Grant corporate technical experts substantial influence and evaluation weight in graduation project defenses, competency certifications, and other assessment processes;

(b) Establish a dynamic adjustment and early warning mechanism for academic programs: Regularly make scientific adjustments to program specializations and enrollment quotas based on data such as future industry trends, graduate employment quality, and employer satisfaction;

(c) Align with internationally recognized engineering education accreditation standards: Drive continuous improvement in program quality to enhance the international competitiveness and recognition of China’s engineering talent.

5.3 Implementation Support and Driving Mechanisms

Regarding implementation support, policy and institutional frameworks are paramount. National and local governments should provide clear institutional safeguards regarding the appointment and evaluation of industry professors, the recognition of faculty engineering practice experience, the distribution of benefits from university-industry collaboration, and the management of interdisciplinary organizations. Second, financial and resource support is essential. A dedicated reform fund should be established, and enterprises should be encouraged to contribute resources through means such as equipment donations and data sharing. Third, organizational and cultural support is required: universities must reform their bureaucratic management structures to foster a teaching culture that encourages innovation, while enterprises should integrate talent development into their strategic plans. Finally, information technology support is crucial, involving the construction of an integrated smart education management platform to digitize project collaboration, resource sharing, and quality monitoring.

Regarding the incentive mechanism, it is essential to establish a sustainable collaborative governance model featuring government guidance, university leadership, and deep enterprise participation. The government should play a guiding and coordinating role through top-level design and policy incentives; as the primary agents of reform, universities must elevate industry-education integration and interdisciplinary training to the level of core institutional strategy, proactively reform internal governance and evaluation systems, and stimulate the intrinsic motivation of faculty to engage in teaching reform;The deep involvement of enterprises is key to the reform, driven by the comprehensive benefits of consistently securing outstanding engineering talent, sharing cutting-edge innovative achievements, enhancing brand reputation, and fulfilling social responsibilities. Therefore, it is essential to design a long-term interest-sharing mechanism based on “joint talent cultivation, shared process management, shared outcomes, and shared responsibility”.

6. Comparison and Insights from Typical Reform Cases at Home and Abroad

To further construct a reform pathway for higher engineering education that addresses future industrial needs, embodies Chinese characteristics, and is scalable and transferable, this study selected eight representative, pioneering, and diverse case studies from both domestic and international contexts for in-depth analysis. These cases cover multiple key dimensions, ranging from conceptual reshaping and systemic restructuring to industry-education integration and enterprise-led initiatives. The aim is to reveal the intrinsic logic, implementation pathways, and core characteristics of reform at the practical level, laying the foundation for subsequent comparisons and the distillation of lessons learned.

The selected international case studies include the New Engineering Education Transformation (NEET) initiative at the Massachusetts Institute of Technology (MIT); Olin College's comprehensive "project-based learning" approach; the Asian model of leapfrog development driven by national strategy and leveraging top-tier international resources at the Singapore University of Technology and Design (SUTD); and the European Institute of Innovation and Technology (EIT)'s Knowledge and Innovation Communities (KICs), a supranational institutionalized system for industry-education integration.

Domestic case studies include Tsinghua University's "Tsinghua Academy" talent development program, representing the systematic exploration by China's top research universities in cultivating elite, long-term engineering leaders; Tianjin University's "New Engineering" development plan, representing a flagship practice of systematic reorganization within China's existing higher education framework; and the emerging research-oriented Southern University of Science and Technology, serving as a "low-inertia" model for systematically integrating modern engineering education concepts within the Chinese context;The industry-academy model of the Huawei ICT Academy at Dongguan University of Technology represents the strong driving force from the industry demand side in engineering talent cultivation.

Based on an in-depth analysis of the above eight cases, a systematic comparison can be conducted across four dimensions—reform drivers, key breakthroughs, organizational safeguards, and challenges—to reveal their intrinsic differences and common logic.

Table 7: Comparison of Domestic and International University Cases:

Comparison Dimensions	Drivers of Reform	Key Breakthroughs	Organizational Support	Challenges Faced
Massachusetts Institute of Technology (MIT)	Responding to the Evolution of Engineering's Essence: Cultivating System Builders and Future Shapers	A complete overhaul of the curriculum and deep interdisciplinary integration	Strong university-wide support, cross-departmental coordination mechanisms, and the establishment of thematic thread management teams	Disrupting traditional disciplinary interests, challenges in transforming faculty roles, and massive investment in project resources
Olin College of Engineering	Redefining engineering education to cultivate innovative, human-centered engineers	University-wide PBL, department-free structure, and an educational partnership ecosystem	Flat, department-free governance; faculty focused on teaching; deep partner involvement	Model difficult to replicate in large traditional universities; extremely high demands on faculty's comprehensive competencies
Singapore University of Technology and Design (SUTD)	Driven by national strategy, leveraging top-tier international resources to achieve leapfrog development	"Grand Design" as the central theme, reverse curriculum logic, and close alignment with industry	Strategic partnership with MIT; unique pillar-major curriculum design	Continued reliance on international partners; balancing cultural integration with independent innovation
EU EIT KICs	Regional integration and innovation strategies, building a transnational alliance for talent development and innovation	Institutionalizing cross-regional industry-education integration, dual-campus learning, and mandatory corporate internships	Consortium agreements under the EU framework, unified degree and quality assurance systems	High complexity of cross-border coordination and harmonization of differences across national education systems
Tsinghua Academy	Cultivating engineering	Establishing a "special zone"	The "Academy Program"	Effective integration and

	leaders and top-tier talent in basic disciplines urgently needed for national strategic priorities	for talent development, integrating science and education, bridging undergraduate and doctoral programs, and strengthening foundational education	Management Committee and special policies for recruitment and training under the "Strengthening Foundations" initiative	outreach between the "special zones" and the main system, and the sustainability of long-term investment
Tianjin University's "New Engineering" Initiative	Responding to the national "New Engineering" strategy to address the disconnect between existing education and industry	Establishing "reform special zones" within the existing system, project-based approaches, and university-industry collaborative innovation	Establishing a Future College or School of Engineering as a vehicle for reform, granting it autonomy	Resistance to collaboration from traditional academic departments, lagging reform of evaluation systems, and the sustainability of corporate participation
Southern University of Science and Technology	Advantages of a newly established university: systematically integrating modern educational concepts to create an innovative model	"Liberal Arts + Major" approach with major-agnostic admissions, residential college mentorship system, and early exposure to research	Advantages of institutional design in a newly established university; flexible faculty hiring and evaluation systems	Balancing quality and scale during rapid development; fostering long-term cultural heritage and brand building
Industry-Academic College Model	Addressing corporate shortages of top-tier talent and building a talent supply chain aligned with future business needs	Driven by corporate needs, deep involvement in the entire training process, and practical standards	Establishment of corporate talent ecosystem departments and signing of long-term strategic cooperation agreements with universities	Balancing Intellectual Property Ownership, University Academic Autonomy, and Corporate Practical Needs

Comprehensive comparative analysis not only identifies commonalities and differences but also distills transferable experiences from diverse global practices that offer significant insights for engineering education reform in China's future-oriented industries. These experiences must undergo careful consideration for localization to effectively guide China's engineering education reform and avoid rejection due to "cultural incompatibility".

First, strengthen the strategic and systematic nature of top-level design. The overall designs of the NEET initiative and Olin College demonstrate that future-oriented engineering education cannot be achieved through piecemeal additions or subtractions to the curriculum; rather, it must involve a top-down, systematic restructuring based on forward-looking assessments of future industrial landscapes and the profiles of engineering talent. Reforms in China's higher engineering education must enhance strategic planning capabilities at both the national and institutional levels, proactively embedding educational frameworks within the national innovation system and industrial development blueprint.

Second, break down organizational barriers and innovate institutional mechanisms. Whether it is MIT's "thematic threads," Olin's "department-free" model, or the Future Technology Colleges at domestic universities, the key to their success lies in breaking through traditional barriers of departmental and disciplinary management. Therefore, the reform of China's higher engineering education must address deep-seated issues in disciplinary management systems, resource allocation mechanisms, and faculty evaluation systems.

Third, we must build an institutionalized, mutually beneficial ecosystem for deep industry-education integration. The European Institute of Innovation and Technology (EIT) and the Industry Academy models demonstrate that the key to deep industry-education integration lies in establishing an institutionalized educational community. Reform of China's higher engineering education requires universities and enterprises to jointly design the entire process,from educational objectives and curriculum systems to graduation evaluations.

Fourth, comprehensively deepen student-centered teaching models based on complex, real-world projects. Practices at Olin and MIT have demonstrated the irreplaceable role of PBL in cultivating complex problem-solving skills, systems thinking, and an innovative spirit. Reforms in China's higher engineering education must promote PBL from an occasional supplement to a routine practice, and from simplified simulations to real-world complexity. This requires collaborating with enterprises to develop authentic industry-based projects, while simultaneously reforming assessment methods to establish a formative evaluation system based on evidence of competencies.

Fifth, foster a "new" teaching culture and institutional environment. The development of outstanding engineering talent requires a safe space for trial and error. China's higher engineering education must focus on reforming the evaluation inertia that overemphasizes standard answers and short-term performance, granting pilot reform units, faculty, and students longer evaluation cycles and greater room for error in teaching management.

Sixth, we must prudently advance the localization of international experiences while guarding against potential "rejection reactions." These primarily manifest as tensions between the individualism emphasized in the West and China's cultural tradition of valuing collectivism, as well as resource constraints arising from the gap between the ideal model of high investment and small class sizes and the reality of China's large-scale engineering education. In response, we should adopt a strategy of gradual integration rather than wholesale transplantation, prioritizing the absorption of core concepts and methods for localized adaptation and embedding. At the same time, we should leverage information technology to reduce the costs of in-depth practical instruction and expand its reach through online collaboration platforms and other means. Ultimately, the success of the reform depends on building a consensus on values and a diverse support network among the government, universities, enterprises, and society, thereby generating a collective force to drive the paradigm shift in engineering education.

7. Conclusion and Outlook

This study systematically reveals a structural disconnect between China's higher engineering education and the demands of future industries. The study found that, in light of the "digitalization, convergence, and innovation" characteristics of future industries, engineering professionals must possess six core competencies: insight into and application of cutting-edge technologies; the ability to solve complex systems; interdisciplinary collaboration skills; digital literacy; a spirit of innovation and entrepreneurship; and a commitment to engineering ethics and sustainable development. The cultivation of these six core competencies cannot be achieved independently at either the undergraduate or graduate level but requires coordinated efforts across both stages. The undergraduate stage focuses on laying a solid foundation, cultivating students' fundamental competencies and learning abilities through a broad disciplinary foundation, systematic engineering training, and introductory project practice. The graduate stage emphasizes deepening and breakthroughs, forging students' innovative capabilities and leadership potential through tackling cutting-edge research topics, solving complex problems, and deep industry-education integration. A seamless transition mechanism must be established between the two stages to avoid gaps or duplication in competency development.

To this end, engineering education reform must transcend piecemeal adjustments. Guided by future industry competency models, it must undertake a systematic and coordinated restructuring across the five dimensions of curriculum, teaching, faculty, practice, and evaluation—spanning both undergraduate and graduate levels. This will establish a full-cycle engineering talent development system characterized by "undergraduate foundation-laying, graduate-level deepening, and lifelong learning through continuous iteration," thereby achieving a fundamental shift in talent development from "adapting to the status quo" to "leading the future."

Looking ahead, future research could further focus on differentiated reform strategies and implementation mechanisms tailored to various regions and types of universities. It should also explore in depth how technologies such as artificial intelligence and digital twins can empower personalized engineering learning and virtual engineering practice. Furthermore, based on long-term tracking and evaluation, a dynamic feedback and optimization model for assessing reform outcomes should be developed to drive continuous iteration and systematic innovation in China's higher engineering education as it responds to future industrial transformations.

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