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Division and integration of theory and practice: Reflections on engineering education in China

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ABSTRACT

This article starts with the basic relationship of "theory and practice" in engineering education and reviews the concepts and practices of engineering talent cultivation in Chinese higher education. It reflects on the measures of engineering talent cultivation in Chinese universities based on the case of "innovative practical education" at Tsinghua University. It points out that the integration of "theory and practice" in the cognition and practice of engineering education in China is gradually moving towards a meaningful fuslon.

Key words: engineering talent cultivation, theory and practice, integration

INTRODUCTION

Currently, China has become the largest country in the world for engineering education. The important mission of Chinese engineering education is to cultivate more and higher quality engineering talents for China and the global community. In China's higher education system, looking at the enrollment, number of students, and number of graduates in undergraduate education, engineering education accounts for roughly one-third of the education system. Therefore, the cultivation of engineering talents is not only one of the most concerned topics in the academic community of Chinese higher education, but also a key issue that has been explored in the long-term practice of Chinese educators.

For decades, China's higher education has been heavily influenced by Western pedagogical concepts. During the 1950s and 1960s, universities in China modeled their engineering programs on European systems, notably those in the Soviet Union and Germany. These models were adapted to align with China's then-industrialized economy, producing highly pragmatic programs closely tied to specific industries or even specific trades. The goals of engineering education at the time were dovetailed with the practical needs of the industrial sector. Since the mid-1990s, as rapid technological development became a global focus, the ability for technological innovation has become a primary indicator of national competitiveness. The economy's demand for "innovative" engineering talents has reached an unprecedented level. "Innovation" is often conceived as stemming from the discovery or proposal of scientific principles, whereas engineering technology is seen as merely an "application" of those scientific discoveries. As Chinese universities seek to infuse elements of innovation into their curricula, they inevitably engage themselves in strategic considerations of the balance between science and engineering.

In the early 21st century, a revolutionary engineering education reform initiative was launched by four universities: Massachusetts Institute of Technology (United States), Chalmers University of Technology (Gothenburg, Sweden), Kungliga tekniska högskolan

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(KTH) Royal Institute of Technology (Sweden), and Linköping University (Sweden). This initiative aimed to redesign coursework and practicums around the four stages of a product's life cycle: Conceive, Design, Implement, and Operate.[1] This pedagogical model fosters students' innovative and creative abilities alongside their foundational knowledge. The approach quickly gained attention, attracting participation from universities of various types and levels in over 30 countries. In China, the engineering education community also shows great interest in the conceiving-designing-implementing-operating (CDIO) model. Represented by schools like Shantou University, many higher education institutions have explored the incorporation of the CDIO model into their engineering talent cultivation processes, which involves systematically redesigning their talent training models. Influenced by the CDIO model,[2-3] many Chinese universities are progressively reforming their curriculum structures and teaching methods.

As globalization continues to evolve, there is a growing need to align China's engineering talent development with international standards. China's endeavor to join the *Washington Accord* also signifies a step-by-step acceptance of international quality standards for "review" and "accreditation" within China's engineering education. Higher education institutions in China are increasingly adopting outcome-based education principles, focusing on results as the standard for quality assessment, which was originally proposed by American scholar William G. Spady in the 1990s. In line with these principles, the Accreditation Board for Engineering and Technology sets globally recognized specific ability and quality requirements for the training of engineering talents in the new era, which are regularly updated to reflect changing industry needs. This has led Chinese universities to reassess the specific objectives of their engineering education programs, clearly define them, and develop targeted strategies and methods to achieve these goals. In 2016, China became a formal member of the *Washington Accord* and has since developed and implemented engineering education accreditation standards tailored to its unique circumstances yet aligned with the principles of the *Washington Accord* across universities nationwide.

To align its engineering education with international benchmarks, China has engaged a diverse coalition of stakeholders–spanning academic institutions, government agencies, and industry–to contribute to a transformative process.

This article dives into China's unique journey of adapting and fine-tuning its engineering educational landscape in response to global trends. While China has various research-oriented universities, institutions like Tsinghua University stand as noteworthy pioneers in educational innovation. Established in 2009, Tsinghua's innovative practical education (IPE) initiative serves not only as a modern approach but as an illustrative case that highlights the ongoing efforts to unify theory and practice in engineering education. Prior to this initiative, the predominant focus was on training engineers capable of applying theoretical understanding in real-world scenarios. Through an in-depth examination of Tsinghua's initiative, this article aims to shed light on the shifting paradigms and approaches in China's engineering education, offering actionable insights to further enhance the cultivation of engineering talents.

THE ILLUSION OF INTEGRATION: HOW TRADITIONAL APPROACHES "COMBINED" THEORY AND PRACTICE

In engineering education, the relationship between theory and practice is a foundational cornerstone. For nearly two decades, the governing principle for navigating this complex relationship in China has been "the integration of theory and practice", readily acceptable to everyone within the field. This principle raises an essential question: "How can we effectively integrate theory into practice in cultivating engineering talents?" Essentially, from today's perspective, this boils down to teaching students how to discover scientific principles and how to apply them creatively in real-world settings. Both the theoretical and practical aspects of engineering education center on addressing this critical issue.

In the 1980s and 1990s, a period marked by deepening educational reforms in China, the engineering education community espoused a dual focus: equipping students with theoretical knowledge while engaging them in practical, hands-on experiences. This means that, besides learning theoretical knowledge at universities, there is a strong emphasis on students' participation in practical production. For example, engineering students at Tsinghua University were required to "tackle real-world engineering problems for their graduation projects", culminating in tangible products. Education was structured in fixed periods: classroom learning for theory and field experiences for hands-on practice. For many years, reforms in Chinese engineering education emphasized the importance of "hands-on practice". These reforms included extending the time dedicated to practicums within the standard academic timeline and, in some cases, even lengthening the entire academic period to create more room for practical experiences. One such approach involved collaborative training programs between universities and enterprises, where students would spend specified durations at the educational institution and in industry.

While the objective of these reforms was ostensibly to better integrate theory into practice, implementation in practice revealed a different picture. In reality, theoretical education and practical training existed in separate spheres, both temporally and spatially. The curricula, content, and scheduling for theoretical studies and practical experience were designed independently. Despite the proclaimed goal of "integrating theory and practice", the reality often fell short of the mark. While theory and practice were intended to be woven together, they often existed in separate compartments–each governed by its own set of rules and timeframes. The term "integration" thus became somewhat of a misnomer, as the actual structure failed to foster any meaningful synergy between theoretical learning and hands-on training. This fragmentation hindered the effectiveness of the education system in cultivating well-rounded engineering talents.

Entering the 1990s, influenced by advancements in technology and the educational philosophy of Western universities, Chinese universities, especially research-oriented universities, began to attach increasing importance to scientific research. Driven by the notion that "scientific discovery equates to innovation" and the public's high regard for scientific research, Chinese universities have increasingly prioritized theoretical knowledge over practical skills. This trend, often described as the "scientification of engineering disciplines", remains a persistent issue in cultivating engineering talents even today. Such an emphasis on theory at the expense of practice has only further widened the gap between the two, ultimately steering the development of engineering talents away from its intended trajectory.

BRIDGING THE DIVIDISION: HOW THE RISE OF THE IPE INITIATIVE MEANINGFULLY UNIFIES THEORY AND PRACTICE

In the wake of rapid technological advancements that continue to reshape society, innovation in educational institutions has never been more crucial. As we entered the 21st century, fostering innovation emerged as a top priority in cultivating elite talents within universities. Recognizing this need for a more innovative approach to engineering education, Chinese universities have embarked on a journey to revisit the long-standing dichotomy between "theory" and "practice", reframe these terms, and reassess their interrelationship within the educational paradigm.

Tsinghua University is at the forefront of this transformation. The university has leveraged its century-long history of educational excellence and its unique pedagogical traits to introduce the IPE initiative. This approach is designed to nurture students' innovative thinking and skills through hands-on learning experiences. Under the banner of the IPE initiative, students are encouraged to formulate questions, engage in research geared toward solving real-world problems, persist in overcoming challenges by applying newly acquired knowledge, and ultimately revel in the "aha" moment that comes from successful problem-solving. This methodological shift not only fosters a sense of achievement and boosts students' confidence but also cultivates their innovative spirit and enhances their creative capabilities.[4]

To institutionalize this progressive approach, Tsinghua University has undertaken comprehensive measures and laid out a structured framework for the IPE initiative. As shown in Figure 1, this framework consists of three key components: a high-level academic platform developed through five building blocks, a tripartite series of educational activities that form the core content of the initiative, and two guarantee mechanisms to guide, motivate, and support students' continuous engagement in innovative practical activities.[4]

Specifically, in terms of disciplinary construction, Tsinghua has built on its engineering heritage to offer a comprehensive array of disciplines in the natural sciences, management, humanities, social sciences, arts, and medicine. This multidisciplinary environment provides fertile ground for implementing the IPE initiative. Moreover, Tsinghua University also continuously refines interdisciplinary directions, forms advantageous discipline clusters, promotes interdisciplinary studies and international cooperation, and creates and expands the space for the growth of innovative talents. High-caliber research platforms, such as national and key national laboratories and research centers in the humanities and social sciences, offer robust infrastructural support for student-led innovative research. The university has also established a dynamic academic exchange ecosystem that includes institutional, cross-institutional, and international forums, conferences, and academic gatherings. To stimulate a vibrant intellectual environment, Tsinghua has institutionalized the allocation of funds to establish special funds, fostering an active academic atmosphere that encourages innovation and facilitates exchange, and motivating students to engage in innovative research.

A cornerstone of Tsinghua's IPE initiative is its world-class faculty, considering the institution's most vital asset for implementation. Through its commitment to attracting and nurturing top-tier educators by internationally competitive mechanisms, the university has amassed a diverse and accomplished faculty deeply involved in the educational process.

The curricula have been designed in three distinct series to foster a research-oriented, problem-solving approach, rather than merely imparting knowledge. These include seminars for first-year students, laboratory inquiry courses, student research training programs, and research-oriented graduate courses. Competitions, lab projects, and mandatory research papers increasingly immerse undergraduates in high-level scientific inquiry,

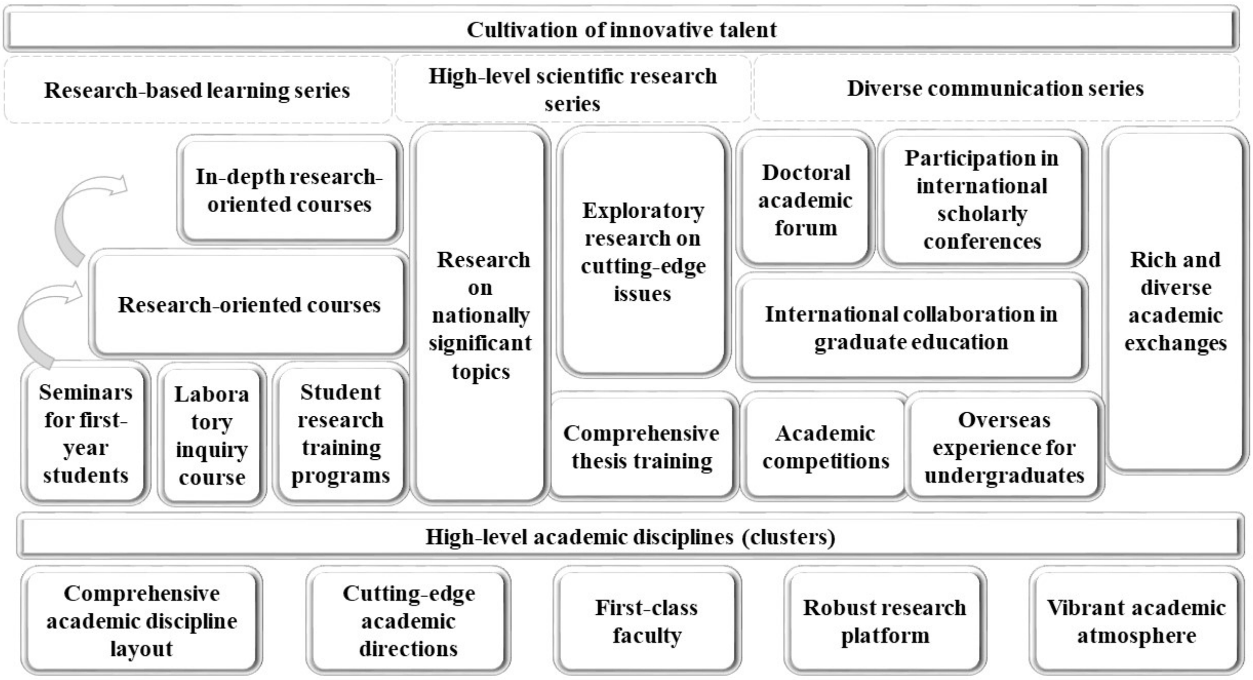

Figure 1. Illustration of the IPE initiative framework (reproduced with permission from Gu *et al.*[4])

offering more systematic research training. Moreover, the university robustly endorses a variety of doctoral student academic forums both within and outside their institution and discipline, and provides special funds to support student participation in international academic conferences, international cooperative training programs, and internships, both domestically and abroad. This well-rounded approach ensures that students are not just confined to academic settings but are also encouraged to engage with society and the global community.

By likening education to "planting", where both genetic factors and external conditions contribute to growth, the IPE initiative enhances the existing talent development ecosystem at Tsinghua. This new framework marries theory and practice in a harmonious blend, essentially erasing the traditional boundaries between intellectual and hands-on learning.

In this model of education, "knowledge" has been redefined to include both theory and practice as integral components. For learners, this means that the two are naturally unified, occurring concurrently in the same educational setting. From a systemic design perspective, the IPE initiative has also blurred the lines between theory and practice. Instead of being viewed as separate entities, they are integrated into a unified educational content. This holistic approach ushers in a new era of engineering education in China that progresses from the granular level of classroom instruction to broader national initiatives, pioneering a more meaningful integration of theory and practice in the cultivation of engineering talents.

THE ENSEMBLE EFFECT: HOW MULTI-STAKEHOLDER COLLABORATION FACILITATES INTEGRATION

Since 2010, China's Ministry of Education has spearheaded the "Excellent Engineer Education Training Plan", selecting a group of premier universities to specialize in cultivating top-notch engineers. These universities engage in tailor-made explorations and designs that align with their unique traditions and characteristics, effectively overhauling the engineering talent development process through a top-down approach. The adopted training model leverages a collaborative relationship between universities and enterprises, featuring three years of on-campus study followed by a year of hands-on experience in an industry setting. While these two phases are still separated in time and space, each is meticulously planned to reinforce the seamless integration of theory and practice. During the on-campus phase, the curriculum is revamped to focus on enhancing practical engineering skills, design capabilities, and innovative thinking. Teaching methods are designed to encourage research-based learning approaches, such as problem-based, project-based, and case-based learning. Additionally, the training program's design integrates industry expertise by inviting professionals to teach courses and mentor students on their graduation projects. The year-long industry experience phase in turn immerses students in real-world settings where they identify problems, develop solutions, and implement them–thereby honing their appreciation of the intricate connections between theory and practice. Particularly noteworthy is the joint mentorship provided by university tutors and industry experts during the students' graduation projects, which are focused on addressing real-world challenges.

Another cornerstone of the "Excellent Engineer Education Training Plan" is measures to cultivate a "dual-expertise faculty", under which instructors who are adept at both theory and practice are recruited. Universities are increasingly adding faculty with engineering experience, insisting that engineering instructors have actual work experience, and actively recruiting industry professionals as part-time teachers. This collaborative effort between academic and industrial sectors is creating teaching teams committed to bridging the gap between theory and practice.

Simultaneously, at the graduate level, a reform pilot project was jointly launched in 2010 by the Ministry of Education and the Chinese Academy of Engineering. This project aims to co-train doctoral students in collaboration with universities and engineering institutes in order to improve the quality of advanced innovative engineering and technical talents. In 2011, the Chinese government established professional doctoral degrees in engineering, laying the groundwork for a systematic educational framework aimed at training high-level engineering talents in specialized fields. Then in 2022, the Ministry of Education, in partnership with the State-Owned Assets Supervision and Administration Commission, launched a plan to support the collaborative development of National Centers of Excellence in Engineering between selected universities and central enterprises. This plan seeks to institutionalize and deepen the integration of industry and academia on a national scale, with the goal of nurturing professionals who not only have a robust foundation in theory but are also equipped with specialized knowledge, engineering ethics, and the capability to tackle complex technical challenges, innovate within their field, and maintain a global perspective.

This series of national moves underscores a transformative shift in the landscape of engineering education: the responsibility for cultivating engineering talents now extends beyond the academic sphere to include both government and industry stakeholders. From the overarching blueprint down to the granular elements of educational delivery, a comprehensive and systemic approach is visibly at play. Various entities are involved, both as architects and active participants, in the educational journey. The evolving dynamic between "theory and practice" is inching closer to a genuine seamless integration. Even the curriculum offered by educational institutions and the competencies expected from educators are undergoing reevaluation and transformation. In essence, the borderlines between theory and practice are gradually dissolving, paving the way for a more cohesive educational experience.

CHARTING THE COURSE AHEAD: FUTURE DIRECTIONS AND CONSIDERATIONS IN ENGINEERING EDUCATION

Since introducing the IPE initiative in 2009, Tsinghua University has been at the forefront of reimagining engineering education. The institution places a growing emphasis on transcending traditional academic silos to foster a more holistic approach to talent development. Similarly, universities across China are undertaking their own unique journeys to revamp engineering education. These efforts include curriculum redesign, the creation of novel partnerships between academia and industry, and the rollout of specialized engineering degrees. Despite these strides, there remain challenges that require further exploration and discussion within the educational community.

First, a key question is how modern engineering education can more effectively harmonize theory and practice. Historically, educational approaches treated these two elements as distinct but complementary, often advocating their "combination". However, as we move further into the 21st century, a wave of educational reforms in China suggests a paradigm shift. The focus is now evolving from a mindset of "separation" to one of "integration", where theory and practice are viewed not as discrete entities but as interconnected components of a unified educational experience. This calls for a systemic overhaul of the educational process to enhance integration.

Second, a pivotal question arises: How can we effectively integrate theory and practice in talent development? The gap between conceptual understanding and practical implementation remains significant. Accepting that theory and practice should be unified, how do we then structure educational platforms, outline the roles of educators and students, and truly synchronize engineering education with real-world needs? These questions pose a fresh set of challenges. Can we dismantle the traditional approach where students consume pre-set content in fixed periods? Should students, who are at the core of educational growth and development, have greater agency in shaping their learning journey? And should universities themselves reconsider their organizational structure and functionalities? In 2020, Stanford University published *Stanford 2025*, introducing innovative concepts like open-loop universities and self-paced learning, which challenge existing educational paradigms and offer valuable insights for exploring the above questions.

Third, what will the future landscape of engineering education look like? Under the impact of artificial intelligence and information technology on the education system, will there be a disruptive transformation in the way humans learn in the future?

Re-evaluating the definition of "intelligence" and distinguishing between "human" and "non-human intelligence" will be foundational issues for future educational endeavors. What types of engineering talents will future society need? How should educational objectives and processes adapt to meet these needs? These are questions that warrant ongoing exploration by education researchers and practitioners.

While China has made significant progress in bridging the gap between theory and practice in engineering education, this comes after two decades of misconceptions and flawed implementations. Faced with lingering challenges and newly emerging issues, the journey to cultivating exceptional engineering talent in China remains long and demanding.

DECLARATION

Author Contributions

Gu BL has accepted responsibility for the entire content of this manuscript and approved its submission.

Conflict of Interest

The author declares no competing interest.

Data Availability Statement

Not applicable.

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