

ORIGINAL ARTICLE

Cultivating outstanding engineers through university-industry collaboration: A case study in Beijing Institute of Technology

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ABSTRACT

In response to China's national initiatives to deepen university-industry collaboration (UIC) and cultivate high-level engineering talents, universities have been tasked with developing innovative training paradigms. The National Superior College for Engineers, established in key universities and enterprises, serve as experimental platforms for synergistic training. This paper presents the "6+1" university-industry collaboration training system implemented in Beijing Institute of Technology (BIT). Drawing on the complementarity between formal contracts and relational governance, the system operationalizes UIC as a structured, multi-level coordination mechanism of joint design, delivery, governance, and evaluation across the full training cycle, embedding collaborative principles into every subsystem and management layer. The "6+1" system systematically integrates seven core components: (1) Top-level design with five integration strategies; (2) Optimized student selection through three matching principles; (3) Collaborative mentorship with two-way engagement; (4) "442" curriculum architecture balancing theory and practice; (5) A four-stage research progression pathway; (6) Eight-category achievement-based assessment standards; (7) Full-cycle process management. This system ensures comprehensive preparation of students through seamless undergraduate-postgraduate articulation, progressive research training, and dual supervision by academic and industrial mentors. Underpinned by substantive university-industry collaboration, after three years of implementation, the program demonstrates significant outcomes: enhanced recruit quality with increased top-tier student enrollment, a high-profile supervisory team comprising 994 members, diversified curriculum with 192 specialized courses and 20 published textbooks, and strong graduate employment with 97% corporate placement rate and notable demonstration effects across peer institutions, offering a transferable operational model for deep university-industry collaboration in engineering education. The case illustrates how formal safeguards and relational trust can be jointly institutionalized to address core UIC deficiencies, offering a transferable operational model for deep university-industry collaboration in engineering education.

Keywords: outstanding engineer cultivation, university-industry collaboration, engineering education, "6+1" training system

INTRODUCTION

University-industry collaboration (UIC) plays a pivotal role in driving innovation, economic competitiveness, and sustainable development by effectively bridging academic research with industrial applications (Organ-

isation for Economic Co-operation and Development, 2019). This collaboration has become increasingly critical in the context of the rapid expansion of graduate education and the transformation of the manufacturing sector. UIC enhances graduate employability through hands-on learning approaches, such as capstone

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projects, and fosters curriculum innovation by aligning educational outcomes with industry needs (Shah & Gillen, 2024). Despite its recognized significance, UIC encounters substantial practical challenges, including structural misalignments between university and industry goals, institutional barriers such as limited autonomy of higher education institutions and bureaucratic complexities (Borah et al., 2021), and persistent mismatches between talent supply and market demand (Gong, 2024). Extending this analysis, three core deficiencies in current university-industry collaboration efforts can be identified: insufficient incorporation into university training programs, weak motivation for enterprise participation, and the absence of sustainable long-term mechanisms (Wang & Yang, 2025). These issues underscore the need for more integrated policy frameworks and synergistic mechanisms to optimize collaboration outcomes and ensure that the expansion of higher education effectively fuels the upgrading of the real economy.

In response to these challenges, the Chinese government has launched a series of top-level strategic initiatives to deepen integration between university and industry through the systematic cultivation of high-level outstanding engineers. A significant milestone was reached in 2022 with the establishment of the first 18 National Superior College for Engineers under a pilot reform program, marking the entry into a structured and scaled phase of high-level engineering talent development (China Education News, 2024). These macro-level efforts represent a structured national response aimed at overcoming systemic barriers and enhancing the coupling between talent supply and strategic industrial demands, thereby driving the transformation from an engineering education powerhouse to a global leader.

Building on this national framework, universities have undertaken the critical mission of creating new paradigms for training outstanding engineering talent. The National Superior College for Engineers, established in 42 universities and 8 large Chinese Central State-owned enterprises, serve as experimental platforms for synergistic university-industry training. Through models such as integrated bachelor-master pathways, alternating work-study phases, and dual supervision by academic and industrial mentors, these institutes effectively leverage universities' strengths in theoretical innovation and enterprises' advantages in engineering practice (Li et al., 2026). As one of the first pilot institutions, Beijing Institute of Technology (BIT) has developed a series of practical innovations in outstanding engineering training over three years. However, these innovations remained at the level of individual practices; this set of practices had not yet been synthesized into a coherent systemic framework, nor had their potentially transferable lessons been extracted as generalizable principles.

This study therefore aims to fill this gap by systematically analyzing BIT's practical innovations and distilling them into a theoretical model, referred to as the "6+1" training system, thereby providing an analytical framework and actionable insights for broader application. Specifically, it asks: How does BIT's "6+1" training system operationalize solutions to the three core UIC deficiencies—insufficient curricular integration, weak enterprise motivation, and lack of long-term mechanisms? What transferable principles and limitations characterize this model?

METHODOLOGY

This study adopts a single-case study design. The BIT "6+1" system is selected as a critical case because it represents an early, mature pilot under China's national reform program, offering rich longitudinal data (2022–2025) for examining how UIC deficits are addressed through institutional design.

Data sources include: (1) Internal policy documents, training plans, and regulation texts issued by BIT's National Superior College for Engineers; (2) Program statistical reports covering enrollment, mentor development, curriculum construction, and graduate employment for cohorts 2022–2025; (3) Third-party media reports and official commendation materials.

The study followed an explanatory-embedded approach. First, the three UIC deficiencies identified by Wang and Yang (2025) were coded as theoretical sensitizing concepts. Second, each component of the "6+1" system was mapped to one or more of these deficiencies. Third, outcome data were examined to assess whether the intended causal logic was supported. Triangulation across document and statistical data was performed to enhance validity.

Theoretical lens

Drawing on Poppo and Zenger (2002), this study adopts the logic of complementarity between formal contracts and relational governance—where detailed agreements foster trust and sustained collaboration refines formal rules (Poppo & Zenger, 2002)—to analyze how BIT's "6+1" system addresses the three core deficiencies of university industry collaboration.

In BIT's "6+1" system, formal contracts are embodied in the tripartite agreements among university, enterprise, and student, the mandatory credit allocation rules such as the 40 percent practice-based component in the "442" curriculum, the bi-weekly co-supervision protocol with defined responsibilities for academic and industrial mentors, and the eight-category outcome-based degree conferral standards. These formal provisions create clear

expectations, specify penalties for non-compliance, and provide legal and administrative safeguards. Relational governance, in contrast, is reflected in the sustained trust developed through repeated joint activities, including the collaborative design and updating of curricula, the mutual sharing of proprietary engineering cases, the active participation of enterprise experts in admission and degree committees beyond contractual requirements, and the joint problem-solving when unexpected mismatches in student interests or technological changes arise. These relational norms enable flexibility and information sharing that no formal contract can fully prescribe.

Crucially, the "6+1" system illustrates the complementary logic identified by Poppo and Zenger (2002). The detailed tripartite agreements and explicit evaluation standards do not crowd out trust; rather, they foster enterprise commitment and deepen relational engagement by reducing the hazards of hold-up and information asymmetry. Conversely, the ongoing collaborative relationship continuously informs the refinement of formal arrangements, such as the periodic revision of course offerings, the optimization of the mentor performance metrics, and the updating of degree application procedures. This virtuous cycle between formal contracts and relational governance directly addresses the three UIC deficiencies identified by Wang and Yang (2025): insufficient curricular integration, weak enterprise motivation, and the absence of sustainable long-term mechanisms.

The "6+1" training system design

The "6+1" model (as shown in Figure 1) is organized into two complementary parts. Part "6" comprises six core training subsystems that directly shape the educational process. Part "1" consists of a management system that provides institutional support and quality assurance across all six subsystems. In this study, UIC is operationally defined as a structured, multi level coordination mechanism in which universities and enterprises jointly design, deliver, govern, and evaluate talent cultivation processes, based on aligned objectives, shared resources, dual supervision, and mutual accountability across the full training cycle. The "6+1" framework operationalizes this definition by embedding UIC principles into every subsystem and governance layer. Each component is analyzed below in terms of the UIC deficiency it primarily addresses, its key design features, observed outcomes, and remaining gaps.

Framework of the "6+1" training system

Conceptually, the "6+1" framework can be understood as a hierarchically integrated and dynamically coupled system for deep university-industry collaboration, rather

than a mere aggregation of discrete components. The six subsystems (Part "6") do not operate in isolation; instead, they form a sequential yet recursive training pipeline that spans from strategic design to outcome evaluation. The top-level design establishes the overarching principles and structural logic, which then cascade into the enrollment mechanism that ensures precise alignment among student backgrounds, academic research directions, and enterprise technical needs. This alignment directly feeds into the supervisory subsystem, where joint mentorship translates alignment into daily guidance. Subsequently, the curriculum architecture and the work–study alternation pathway operationalize the training content and experiential learning sequence, respectively. These two subsystems are mutually reinforcing: the curriculum provides theoretical and methodological tools that are contextualized and tested during enterprise-based practice, while authentic engineering challenges from work–study phases feed back into curriculum updates. Finally, the assessment subsystem closes the loop by defining achievement-based degree criteria and providing structured incentives, thereby generating data and feedback that inform continuous improvement in all preceding subsystems.

Part "1", the management system, functions as the enabling infrastructure that permeates and sustains the entire framework. Unlike a passive administrative layer, it actively coordinates cross subsystem dependencies through grid based regional oversight, tripartite agreements, integrated mentor performance metrics, and a dedicated degree evaluation subcommittee. This management system resolves operational fragmentation and ensures procedural consistency, making the six subsystems not only theoretically coherent but also practically executable. In essence, the "6+1" framework embodies a system of systems logic: the six subsystems generate the educational value chain, while the management system provides the governance, resource, and quality assurance mechanisms that enable the chain to function as a resilient, adaptive, and scalable whole. This conceptualization moves beyond a static checklist of features to highlight the causal and operational interdependencies that underlie BIT's successful implementation of university-industry collaboration. Building on the complementarity framework, the analysis below examines how each component weaves together formal contracts and relational governance to address the three UIC deficiencies.

Detail of the "6+1" training system

Top-level design: Five integration strategies in cultivation

Since all students admitted to the National Superior College for Engineers in 2023 were outstanding undergraduates with exemption of examinations, an integrated

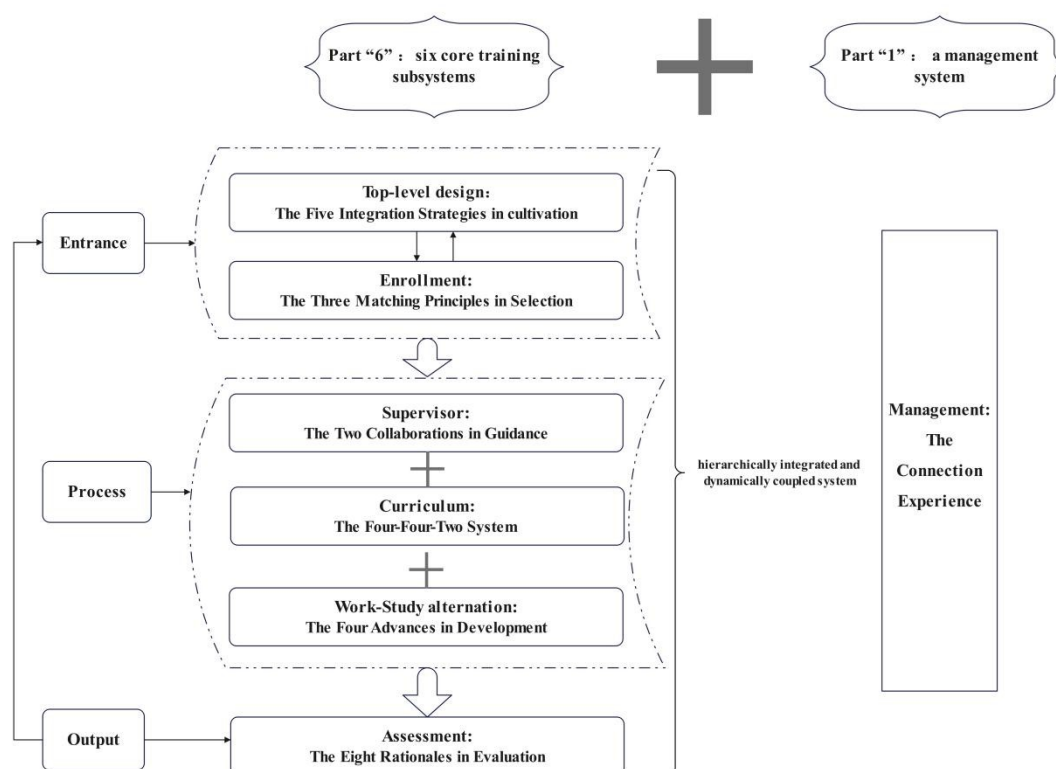


Figure 1. The "6+1" training system framework.

undergraduate-postgraduate pathway has been implemented. Master's students follow a sequential structure comprising one year of senior undergraduate study, one year of graduate coursework, one and a half years of engineering practice, and a final six months dedicated to outcome validation. Doctoral students adhere to a modified and extended version of this framework, which uses the final undergraduate year to facilitate early engagement in graduate-level courses and foundational engineering skill development (as shown in Figure 2). This **cultivation integration** directly addresses the deficiency of insufficient incorporation of university-industry collaboration into the training system.

Based on this temporal foundation, **curriculum system integration** restructures course credits through three reductions and three enhancements, reallocating space from redundant lectures to technical practice and industry co-taught courses. Concrete mechanisms include a competition-based rule that allows master's students who win a provincial or ministerial innovation award with a top-three team ranking to replace one elective course for two credits and a grade of 85. University-industry co-taught courses carry a minimum requirement of six credits for master's students and two credits for doctoral students, with a

wide selection available. Students may also choose electives from the entire university course catalog.

To ensure that theoretical learning translates into hands-on capability, **practical training integration** shifts graduate training forward to the final undergraduate year through a cross-disciplinary comprehensive design course that spans two semesters. The course adopts a hands-on project based model. Students who pass with excellent results may use their project outcomes to replace the traditional undergraduate thesis, thereby avoiding duplicate work and entering their supervisor's research group early to participate in graduate-level research tasks.

Parallel to technical training, **values integration** weaves professional ethics and corporate culture throughout the process through structured activities. These include visits to historical exhibitions and heritage sites, lectures by distinguished scholars and leading industry engineers, exposure to advanced technological achievements, as well as organized group activities and enterprise-based safety and corporate culture training. The university's revolutionary heritage is thus blended with professional ethics and industrial values.



Figure 2. Framework of cultivation integration.

Finally, **management system integration** binds these four streams together. It covers joint selection and performance evaluation of academic and industry mentors, student conduct and enrollment regulations, support for curriculum and textbook development and practical activities, detailed degree conferral rules, merit-based scholarship and stipend evaluation, and organized group activities. A grid-based management model is implemented across regions, appointing part-time regional coordinators and peer leaders to maintain oversight and localized support for students distributed across multiple enterprise sites.

These formal arrangements function as formal contractual safeguards by specifying timelines, credit allocation, substitution rules, and procedural responsibilities. The sustained co-design of courses, hands-on projects, shared value activities, and peer networks build relational governance through trust, information sharing, and collective identification.

Enrollment: Three matching principles in selection

The admission process follows a recommendation based mechanism. A tripartite agreement among the university, the enterprise, and the admitted student is finalized upon enrollment. The procedure aims for precise matching along three dimensions: the academic supervisor's research direction, the enterprise supervisor's technical domain, and the student's prior disciplinary training. The early specification of enterprise requirements and the formal tripartite agreement function as formal contractual safeguards, reducing information asymmetry and signaling commitment. The involvement of industry experts in joint evaluation panels and pre-enrollment lectures by corporate representatives build relational governance through direct interaction and shared expectations. Together, these mechanisms enhance

student-enterprise fit and encourage sustained enterprise engagement.

This initiative employs a multi-dimensional incentive framework. A dedicated Outstanding Engineers scholarship is offered, supplemented by competitive enterprise research stipends and living allowances. These financial provisions function as formal contractual safeguards that reduce economic barriers and signal the value placed on admitted candidates. To mitigate information asymmetry, the program organizes a lecture series by human resource leaders from partner enterprises. These sessions cover research directions, platform resources, support conditions, and career incentives including preferential policies for staying with the firm after graduation. In addition, current or former students who have completed enterprise placements are invited to share their experiences and insights. These interactions build relational governance through direct communication, peer influence, and shared narratives of professional growth.

Statistical data indicate that the proportion of students ranked in the top 20% of their undergraduate majors increased by 30% from the 2023 to the 2024 cohort, suggesting a change in fit. Nevertheless, the matching process does not fully capture students' long-term career preferences, which may contribute to the non-retention rate discussed below.

Supervisor: Two collaborations in guidance

Mentor selection follows a dual pathway with a focus on alignment between the two supervisors. The academic supervisor's research direction and the industry supervisor's technical domain must be complementary. University based mentors are chosen for strong academic records and engineering experience; industry mentors are

technical experts such as chief engineers or project leaders. Selection proceeds through application, pre-screening, committee evaluation, and formal appointment, with regular training provided. These formal criteria and procedures serve as formal contractual safeguards that ensure role clarity and quality. By deliberately pairing complementary expertise, the mechanism also fosters relational governance: mutual respect and trust are more likely to grow when each mentor recognizes the other's distinctive value, creating a solid foundation for collaboration (Li et al., 2022).

The two supervisors are required to communicate at least once every two weeks, with joint responsibilities including training plan development, milestone review, research topic selection, and practice guidance. This mandatory rhythm creates predictable accountability, directly addressing weak enterprise motivation. The recurring interactions build relational governance through information sharing and joint problem-solving. Formal rules ensure regular engagement, while relational trust makes that engagement productive and flexible, reducing the need for further oversight. Together, they enable effective dual supervision throughout the training process.

Curriculum: Four-four-two system

A dedicated curriculum architecture has been established to enhance professional knowledge and practical competence. The innovative 442 framework allocates course credits as follows. Forty percent are devoted to foundational theory and degree core courses, strengthening mathematical principles and disciplinary fundamentals. Another forty percent consist of technical practice modules and courses delivered by enterprise experts, including joint engineering case studies and hands-on technical training. The remaining twenty percent cover frontier interdisciplinary and cross-specialization courses, broadening professional perspectives. In addition to this content structure, AI literacy courses are promoted through general education offerings, and structured self-study options are available to support personalized learning trajectories. Teaching methods have been reformed to adopt smart education platforms, with active learning modalities such as project based learning, case based instruction, and seminar style discussions.

The mandatory forty percent credit allocation for practice based and enterprise taught courses functions as a formal contractual safeguard. It guarantees a minimum level of industry input and ensures that university industry collaboration is structurally embedded, not optional. The sustained co delivery of these courses by academic faculty and enterprise experts creates repeated interactions, which build relational governance through

trust, information sharing, and joint curriculum refinement. The formal ratio triggers regular collaboration, while relational trust makes that collaboration genuinely productive, leading to continuous updates of case studies and teaching methods. This complementary design directly addresses the deficiency of insufficient curricular integration.

Work-study alternation: Four advances in development

A four-stage progressive pathway is structured following the principle of moving from simple to complex, from imitation to innovation, and from campus to industry. Stage one, undergraduate project based design, uses interdisciplinary comprehensive design courses as the core platform. Students from different majors such as mechanical engineering, automation, computer science, and artificial intelligence are mixed into teams, receiving multi-disciplinary faculty guidance through group seminars and monthly reports. This stage covers basic engineering operations, instrument use, literature review, and solution design. Building on this foundation, stage two, graduate research thinking cultivation, moves students into research groups early to participate in faculty-led projects or national level research platform tasks, completing the full cycle from project initiation to testing. Stage three, immersive enterprise R&D, places students in partner enterprise R&D centers to independently undertake specific research tasks, confronting real engineering challenges and mastering deployment and fault diagnosis. The journey culminates in stage four, culminating synthesis, where students participate in engineering innovation competitions or apply for youth research funds, transitioning from project participants to innovation leaders. The cumulative logic ensures that the output of each stage becomes the input for the next, preventing the common UIC problem where enterprise projects are either too simple or too complex. For the 2022 cohort, the retention rate within the original cooperating enterprise or its affiliated group reached 68 percent, higher than typical internship to employment conversion rates.

These four stages embed formal contractual safeguards through clear milestones, required activities, and progression criteria. The staged structure creates a predictable, cumulative pathway that encourages enterprise commitment. At the same time, interdisciplinary teamwork, collective mentoring, and extended enterprise immersion build relational governance through trust, peer learning, and joint problem-solving. Together, they address the deficiency of short term episodic engagement.

Assessment: Eight categories in evaluation

Three institutional mechanisms support the outcome-based degree evaluation system. First, aligned with the *Degree Law of the People's Republic of China* and the competency standards of the Engineering Education Steering Committee, detailed implementation rules for degree application have been formulated. These rules specify the application procedure, achievement requirements, and evaluation methods. Eight categories of contributory achievements are recognized: academic publications, invention patents, international or national standards, research awards, competition prizes, technical appraisals, and functionally applied new products or software with demonstrated practical use. Explicit standards define the graduate's role and the required volume of achievements, ensuring operational clarity.

Second, for degree applications based on practical achievements rather than a traditional thesis, a multi-tiered validation protocol is required. The training institution must convene a panel of at least seven external peer experts, with no more than thirty percent originating from the host institution, to evaluate the practical outcomes and produce a formal statement identifying the candidate's specific tasks and innovative contributions. Subsequently, a joint committee of university and enterprise experts reviews the practical outcomes, the accompanying report, and the peer assessment. Only after passing this stage does the candidate proceed to the final oral defense, where a degree committee examines all materials and renders a decision.

Third, a dedicated Engineering Master's and Doctoral Degree Evaluation Sub-committee has been established, composed of thirty-three members including eleven industry experts. This sub-committee reviews all degree application materials before submitting them to the university's central degree committee for final approval.

These three mechanisms embody the complementarity between formal contracts and relational governance. The detailed implementation rules, the eight-category achievement framework, and the explicit role and volume standards function as formal contractual safeguards. They reduce ambiguity about what counts as a legitimate degree outcome and create transparent, predictable criteria that signal to both students and enterprises that practical engineering contributions are valued equally with academic publications. The external peer review protocol and the joint university-industry evaluation committee add further formal structure, ensuring academic rigor and procedural legitimacy. At the same time, the active participation of industry experts in the peer review panel, the joint evaluation committee, and the degree sub-committee fosters relational governance. Through repeated interactions in

evaluating real world engineering outcomes, university and industry members develop shared norms, mutual trust, and a common understanding of quality. This relational trust makes the formal process more meaningful and reduces the likelihood of purely ritualistic compliance. Thus, the overall design directly addresses the deficiency of weak enterprise motivation by giving industry a structured voice in degree evaluation while simultaneously building relational foundations for deeper collaboration.

Management: Connection experience

Three management mechanisms ensure operational coherence across the training process. First, an innovative grid-based management model has been established, combining a part-time regional supervisor system with a senior peer leader system. Based on the geographical distribution of partner enterprises, thirty committed mid-career faculty members are appointed as part time regional coordinators. They maintain regular contact with both enterprises and stationed students, conducting site visits to monitor research progress, workplace conditions, and institutional support. Meanwhile, outstanding senior students are designated as peer group leaders within each region. They organize local seminars and discussions, creating a peer learning community, identifying concerns, and enabling rapid feedback loops. This two-tier structure provides continuous oversight and localized support without requiring full-time on-site faculty.

Second, a structured co-curricular framework broadens students' intellectual and professional perspectives. Each student is required to attend five high level academic lectures, participate in two thematic seminars on professional ethics and social responsibility, undertake one social practice activity, and join at least one international academic exchange. These activities ensure holistic competency development beyond technical training.

Third, a comprehensive regulatory system has been established. Key documents include the tripartite agreement governing rights and responsibilities of the university, enterprise, and student; detailed regulations for scholarship and stipend allocation; student registration and academic status management rules; formalized incentive and accountability mechanisms for mentors; and guidelines for ideological and organizational development. These documents collectively provide a stable governance foundation for the entire training pipeline.

These management mechanisms embody the complementarity between formal contracts and relational governance. The grid-based oversight structure, the co-curricular credit requirements, and the comprehensive regulatory documents function as formal contractual

safeguards. They clarify roles, responsibilities, and procedures, reducing operational ambiguity and ensuring procedural consistency. The tripartite agreement and mentor accountability rules create binding expectations that encourage enterprise commitment. At the same time, the regional coordinator and peer leader networks foster relational governance through regular face to face interactions, information sharing, and mutual assistance. The peer learning community and feedback loops build trust and collective problem solving capacity among students dispersed across multiple sites. The structured co-curricular activities, while formally required, also create shared experiences that strengthen group identification and professional norms. The formal grid provides the skeleton, while relational trust and peer support make the management system function smoothly with low administrative overhead. This complementarity directly addresses the challenge of maintaining academic oversight when students are scattered across enterprise locations, while simultaneously reducing the need for heavy bureaucratic control.

OUTCOMES

As of June 2025, BIT has achieved excellent outcomes in its Engineering Master's and Doctoral Special Training Program, including quality of graduate recruits, development of supervisory team, core curriculum construction, postgraduate employment and demonstration effect.

BIT is a national leader in terms of enrollment scale. From 2022 to 2025, the program has seen a significant increase in the number of cooperation units, alongside a continuous refinement in training orientation that has become more aligned with industry needs and interdisciplinary development (as shown in Figure 3). To proactively attract high-caliber undergraduate talents to participate in this reform initiative, the university has implemented a multi-faceted promotion strategy, including dissemination of corporate partnerships, research areas, financial subsidies and welfare packages, supportive academic resources, as well as experience-sharing of outstanding postgraduates from the program. Since 2023, all enrolled candidates have been admitted through the recommendation-based admission channel, with the overall quality of recruits demonstrating a steady improvement. Specifically, for the 2024 cohort, the proportion of students ranked among the top 20% of their undergraduate majors increased by 30% compared to the 2023 cohort, reflecting the program's enhanced appeal to high-achieving graduates. This improvement is temporally associated with the introduction of the three matching principles. From the complementarity perspective, the early specification of enterprise requirements and joint evaluation panels serve as formal contractual safeguards

that reduce pre-enrollment information asymmetry. The involvement of enterprise experts in the admission process and the experience-sharing sessions with former interns build relational governance by signaling commitment and fostering trust. These formal and relational mechanisms jointly enhance the program's appeal to high achieving students.

In terms of supervisory team development, the program has established a high-level university-industry collaborative supervisory team, with a well-structured composition of academic and industrial mentors. Specifically, the team includes internal university supervisors, among whom over 60% hold the title of national-level leading talents—reflecting the strong academic foundation of the supervisory cohort. Meanwhile, the industry supervisors consist of key industrial professionals, with chief model designers and technical leaders accounting for more than 20%, ensuring close alignment with industrial practice needs. Additionally, 23 senior industry experts have been integrated into the teaching process to supplement theoretical instruction with practical insights. Notably, the structure of the supervisory team has undergone continuous optimization, and the effectiveness of collaborative guidance between university and industry supervisors has been significantly enhanced, laying a solid foundation for high-quality talent cultivation in engineering fields. This outcome is consistent with the design of the communication protocol and the alignment of performance metrics. The bi-weekly communication requirement functions as a formal contractual safeguard that ensures regular interaction, while the sustained joint decision making over training plans and milestone reviews builds relational governance through trust and shared accountability. Together, these complementary mechanisms appear to have transformed nominal co-supervision into more substantive collaboration.

In the domain of curriculum construction, intensive university-industry collaboration has yielded substantial achievements across three core dimensions: course construction, teaching material compilation, and engineering case development—key pillars of high-quality engineering education. For the Engineering Master's and Doctoral Program, the specialized courses have been developed, with a diversified structure tailored to both academic rigor and industrial applicability: the digital core courses have been launched on the Xuetang Online platform for open access, complemented by university-developed theoretical courses, university-industry co-developed interdisciplinary courses, and enterprise-developed technical practice courses that emphasize hands-on industrial skills. Additionally, 20 engineering and technical textbooks have been compiled and formally published, providing systematic knowledge support for program teaching. In terms of case development, the program has achieved remarkable recog-

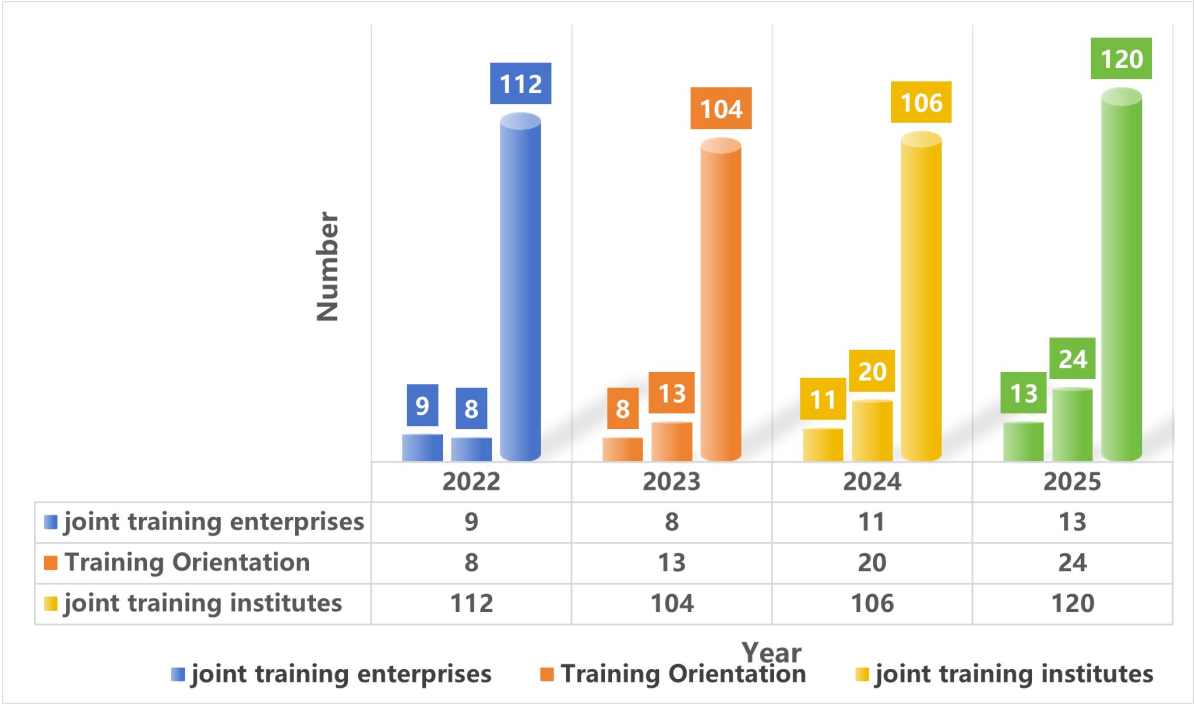


Figure 3. The number of cooperation units and training orientation through 2022 to 2025.

dition: 10 representative cases have been included in the Case Library of China Academic Degrees and Graduate Education Development Center, while 10 high-quality university-level engineering cases have been constructed to bridge theoretical learning with engineering scenarios. These outputs are consistent with the logic embedded in the "442" curriculum framework. The mandatory 40 percent credit allocation for practice based and co-delivered courses serves as a formal contractual safeguard that guarantees industry input. The sustained co-development of cases and textbooks over multiple semesters simultaneously builds relational governance through shared ownership and iterative refinement.

In terms of graduation and employment, the 2022 cohort of engineering master's students achieved a corporate placement rate of 97%, an overall postgraduate employment rate of 100%, and a retention rate within the original cooperating enterprise or its affiliated group of 68%. Prior to the graduation of the engineering master's students in the 2022 cohort, the newly established Engineering Master's and Doctoral Degree Evaluation Sub-committee conducted rigorous oversight of academic quality, ultimately approving a full cohort of master's degrees. Notably, among candidates who applied for master's degrees based on product design works and related technical reports, the proportion of those awarded university-level excellent master's theses was twice that of students from other disciplines and programs across the university. This finding suggests

that the eight-category outcome-based evaluation system does not lower standards but rather recognizes high-quality practice-based work, as the multi-tiered peer validation protocol ensures academic rigor while valuing non-thesis outputs. Overall, the program's diversified outcome evaluation system and standardized operational mechanisms have effectively ensured the quality of engineering talent cultivation.

The Engineering Master's and Doctoral Special Program has demonstrated significant impact, attracting media interviews and reports, receiving research visits from numerous universities, and being invited to deliver reports at various institutions. This achievement was recently recognized with an Outstanding Case honor in the 2025 Excellent Engineer Training program announced by the China Consortium of Excellent Engineer Training. Over the past two years, the program has been interviewed and covered by prominent media outlets including Outlook Weekly, Guangming Daily, Global Times, and China Education News. It has hosted research delegations from more than 20 leading universities nationwide. Additionally, the program has been invited to deliver keynote speeches and reports at academic forums, peer universities, and key industrial groups.

DISCUSSION

This study examines BIT's "6+1" model as a response to the three core UIC deficiencies identified by Wang and Yang (2025): insufficient curricular integration, weak

enterprise motivation, and lack of long-term sustainable mechanisms. The findings show that the model combines multiple formal contractual safeguards—including tripartite agreements, integrated undergraduate graduate pathways, mandatory bi-weekly co-supervision protocols, the "442" credit allocation rule, eight-category outcome based degree standards, and grid-based management with defined roles—with relational governance developed through sustained co-design of courses, joint problem solving in enterprise projects, peer leader networks, shared value activities, and repeated interactions in admission and degree committees. In line with Poppo and Zenger (2002), these two governance mechanisms function as complements rather than substitutes. Formal rules create predictable accountability and reduce information asymmetry; relational trust enables flexibility, information sharing, and mutual adjustment that no contract can fully prescribe. The "6+1" system thus operationalizes complementarity across the entire training chain, from enrollment to degree evaluation.

Comparisons with international models reveal both convergences and divergences. In Germany, the Fachhochschulen mandate industry internships and require professors to have substantial professional experience outside academia (Hu & Song, 2025). This approach ensures practical relevance but typically does not institutionalize dual mentorship or include industry experts in degree evaluation committees. BIT's model goes further by embedding enterprise mentors in governance structures and mandating co-supervision, thereby creating shared accountability across the entire training process. Additionally, BIT's use of outcome diversification and grid management extends beyond typical German practice. From the complementarity lens, the German model relies more heavily on formal individual mandates and less on ongoing relational governance, whereas BIT systematically builds both.

In the Anglo-American context, cooperative education programs integrate work terms into the academic curriculum, often alternating study and paid work placements (Shah & Gillen, 2024). These programs excel at developing employability skills but rarely extend industry involvement to curriculum co-design or degree outcome validation. BIT's "6+1" system addresses these gaps through multiple complementary mechanisms: the "442" framework creates structural space for industry input; the four-stage research practice pathway builds cumulative, multi-year engagement; the eight-category assessment validates practice based outcomes; and the grid model sustains oversight across dispersed sites. A distinctive feature is BIT's explicit attention to the long-term mechanism deficiency, which is less frequently theorized in Western UIC literatures.

Nevertheless, the BIT model's transferability is conditioned by institutional and economic factors. The program relies on large Chinese central state-owned enterprises (SOEs) with long planning horizons, stable R&D funding, and policy alignment with national talent development strategies. In market-driven economies where small and medium-sized enterprises (SMEs) dominate, the same level of enterprise commitment may be difficult to secure. Moreover, the recommendation-based admission system is specific to the Chinese higher education context, limiting direct replication elsewhere. From a theoretical perspective, this suggests that the complementarity between formal contracts and relational governance is itself embedded in broader institutional environments. In contexts where legal enforcement is weak or enterprise turnover is high, formal safeguards may lose their effectiveness, and relational governance might need to substitute rather than complement. The BIT model has not been tested under such adverse conditions.

These limitations point to avenues for future research. Comparative studies could examine how similar formal relational combinations function in different governance and economic contexts, and whether decentralized models like BIT's grid management can be adapted to non-SOE or SME settings. Future work should also investigate the efficient frontier of complementarity: the minimal formal structure needed to initiate relational governance, and how formal rules might be adjusted as trust matures. Other promising directions include testing whether periodic relational audits could reduce administrative costs without undermining complementarity, conducting component level experiments to identify the most impactful design elements, and collecting longitudinal outcome data to strengthen causal inference.

CONCLUSION

This study has analyzed BIT's "6+1" *university-industry collaboration training system* for cultivating outstanding engineers, which encompasses seven core components: top-level design with five integration strategies, optimized student selection through three matching principles, collaborative mentorship with two-way engagement, "442" curriculum architecture balancing theory and practice, a four-stage research progression pathway, eight-category achievement-based assessment standards, and the establishment and improvement of a full-cycle training process management system. Viewed through the lens of complementarity between formal contracts and relational governance (Poppo & Zenger, 2002), the system operationalizes formal safeguards—such as tripartite agreements, credit allocation rules, co-supervision protocols, and outcome-based degree standards—alongside relational trust developed through

sustained co-design, joint problem solving, peer networks, and shared value activities. The system is characterized by systematic comprehensiveness, strong operability, and effective implementability, providing a robust framework for cultivating high quality engineering talents.

The success of the program rests on four pillars. First, systematic top-level design with integrated pathways creates a predictable structure that enables relational trust to accumulate. Second, enterprise participation is secured through a combination of formal agreements and mutually beneficial long-term mechanisms, illustrating how formal safeguards encourage relational engagement. Third, progressive cultivation from undergraduate to graduate stages, with increasing research complexity, builds cumulative competence and shared ownership. Fourth, grid based refined management with regional coordinators and peer leaders sustains oversight while fostering peer based relational governance. These features align with the core characteristics of China's emerging engineering education discipline as identified by Zhang et al. (2025) "professionalization, institutionalization, and disciplinization."

Persistent limitations include the model's reliance on large state-owned enterprises and a centralized admission system, which raise questions about its transferability to small and medium sized enterprises or more market driven contexts. As discussed in the previous section, international comparisons suggest that while the BIT model shares goals with German and Anglo-American UIC approaches, its systematic integration of formal contracts and relational governance offers distinctive insights for engineering education. Future research should examine the efficient combination of these two governance mechanisms across different institutional settings and explore adaptive designs that adjust formal rules as trust matures. Continued efforts to refine research on engineering talent cultivation will yield new perspectives and practical insights for advancing outstanding engineering talent globally.

DECLARATION

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Author contributions

Mingei Li, Developed the research concept, designed the main research framework, writing-original and revised draft preparation. Yuchao Qiu, Writing-original, data collection and analysis, visualization, writing-reviewing and editing. Xiaoli Liu, Writing-original, data analysis, visualization, writing-reviewing and editing. Junzheng Wang, Conceptualization, research questions formu-

lation, editing and supervision. Wei Xue, Conceptualization, research questions formulation, editing and supervision. Shilei Wei, Conceptualization, data collection, editing and supervision. All authors have read and approved the final version of the manuscript.

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Ethical approval

Not applicable.

Informed consent

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Conflict of interest

The authors declare no competing interest.

Use of large language models, AI and machine learning tools

None.

Data availability statement

No additional data.

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