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Exploration and Practice of "Interdisciplinary, Cross-platform, Multi-objective" Teaching Reform Driven by the "Question-Knowledge-Practice-Cultivation"

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Abstract: To address major challenges in current engineering education, including the disconnection between knowledge acquisition and engineering demands, limited interdisciplinary integration, the separation of practice from knowledge, and insufficient integration of value cultivation, this study is grounded in the national strategy of building a manufacturing powerhouse and takes additive manufacturing topology optimization design as its core focus. It proposes and validates a new teaching paradigm driven by the "Question-Knowledge-Practice-Cultivation" (QKPC) framework. Through the establishment of a collaborative educational mechanism characterized by interdisciplinary integration, cross-platform coordination, and multi-objective alignment, this model effectively breaks down disciplinary barriers among materials science, mechanics, mechanical engineering, and computer science. It integrates previously fragmented teaching, research, and engineering resources, and constructs a collaborative sharing mechanism linking industry, education, and research, and scientific research. Practice has demonstrated that this model significantly enhances students' ability to solve complex engineering problems and realizes the deep integration of technical competence with engineering ethics, craftsmanship, and social responsibility. It provides a replicable and scalable pathway for cultivating interdisciplinary and innovative engineering talent.

Keywords: QKPC model; Interdisciplinary integration; Engineering education; Additive manufacturing; Teaching reform

1. Introduction

Amid profound changes and growing turbulence in the international landscape, a new wave of technological revolution and industrial transformation is accelerating. National strategies and industrial development have generated an urgent demand for interdisciplinary engineering talent equipped with interdisciplinary integration capabilities, innovative practical competence, and a strong sense of patriotism and social responsibility [1]. However, the traditional undergraduate engineering education has long been constrained by structural contradictions, including disciplinary fragmentation, the separation of knowledge from practice, and an overemphasis on technical training at the expense of moral cultivation. The limitations of teacher-centered, classroom-centered, and textbook-centered approaches, together with excessively specialized disciplinary divisions, insufficient interdisciplinary integration, and the disconnection between practical teaching and industrial needs, have become increasingly prominent. As a result, students are often positioned as passive recipients of knowledge and lack the intrinsic motivation to explore real engineering problems.

A core mission of new engineering education is to respond effectively to ongoing industrial transformation. However, under the traditional educational model, excessively narrow disciplinary segmentation and weak interdisciplinary interaction have contributed to the fragmentation and isolation of knowledge domains. Students' learning is often confined to a single disciplinary perspective, such as mechanics, materials, or mechanical engineering, which makes it difficult for them to develop the systematic thinking required to address highly integrated modern engineering tasks, such as additive manufacturing topology optimization. As a consequence, a widening gap has emerged not only between knowledge and practice, but also between knowledge transmission and value cultivation [2]. At the same time, the decentralization and fragmentation of teaching resources have substantially weakened the effectiveness of practice-oriented education. In many universities, research platforms and practical training bases are distributed across different departments, resulting in limited resource mobility and the absence of effective mechanisms for interdisciplinary integration. Such fragmentation directly contributes to a serious mismatch between practical teaching and the real demands of industry. Existing studies have shown that when engineering education fails to keep pace with cutting-edge industrial development, the quality of talent cultivation can hardly satisfy national strategic expectations for innovative talent [3]. Furthermore, current engineering education systems generally exhibit an imbalance that prioritizes technical competence over the cultivation of character and values. Under the pressure of intensive professional coursework, engineering ethics, craftsmanship, and patriotic values are often marginalized or reduced to formalities. The absence of value guidance not only blurs students' awareness of the social responsibility of engineering professions but also leaves them without sound value judgment when faced with complex engineering decisions, making it difficult for them to develop the aspiration and commitment to contribute to the nation through science and technology.

In summary, a significant capability gap and value disconnect have emerged between talent cultivation and industrial demands. Establishing an effective educational approach and a sound talent cultivation system has become a critical task in the national agenda for building a strong education system [4]. To break this deadlock, it is imperative to construct a new collaborative educational paradigm driven by engineering problems, supported by interdisciplinary integration, and guided by value cultivation, thereby enabling a fundamental transition from single-skill training to holistic human development. Based on this understanding, the Institute of Advanced Structure Technology of Beijing Institute of Technology, drawing on its disciplinary strengths in additive manufacturing and composite materials, has developed an interdisciplinary teaching reform model driven by "Question-Knowledge-Practice-Cultivation" (QKPC), aiming to systematically address the above-mentioned educational challenges.

2. A new educational philosophy driven by QKPC

2.1. Establishment of the new educational philosophy

In response to the national strategy demand for interdisciplinary and innovative engineering talent in the new era of building a manufacturing powerhouse, and targeting the persistent problems in traditional engineering education, including the disconnection between knowledge and practice, insufficient disciplinary integration, and inadequate value cultivation, this study breaks away from conventional discipline-centered and knowledge-centered educational thinking [5]. By closely following the practical laws of engineering education and the developmental pattern of talent growth, it establishes a new educational philosophy driven by "Question-Knowledge-Practice-Cultivation" and guided by an interdisciplinary, cross-platform, and multi-objective orientation. With talent cultivation as its fundamental purpose, this philosophy deeply integrates the logic of an internally driven closed loop with a collaborative implementation system, thereby reconstructing both the educational logic and the operational framework of engineering education. It realizes a fundamental shift from single skill training to all-round education, from passive knowledge transmission to active problem exploration, and from fragmented resource-based teaching to coordinated system-based education, providing a systematic and practice-oriented guiding philosophy for the reform of practice-based higher engineering education in the new era.

The core support of this philosophy consists of two dimensions, namely the internal driving mechanism and the implementation pathway. These dimensions are interrelated and progressively linked, forming a complete and operational educational system. At the level of educational logic, the QKPC closed-loop framework of "Question-Knowledge-Practice-Cultivation" is established, breaking away from the traditional model that starts from knowledge transmission. Instead, it takes real engineering problems from industrial frontlines and core technological issues in national strategic fields as the starting point, thereby stimulating students' intrinsic motivation for knowledge acquisition and practical exploration. Based on the needs of engineering problem solving, the learning of multi-disciplinary knowledge becomes the essential support for addressing problems, promoting the interdisciplinary reconstruction of knowledge and active learning. This abandons fragmented knowledge accumulation within a single discipline and realizes demand-driven integration, systematic construction, and comprehensive mastery of knowledge. Practice then serves as the essential pathway through which knowledge is applied and competence is developed, enabling students to test knowledge, optimize solutions, refine skills, and achieve the integration of knowledge and action. Cultivation represents the ultimate destination of education, embedding value shaping throughout the entire process of problem exploration, knowledge acquisition, and practical application, thereby elevating technical competence training toward the development of engineering literacy and value orientation. These four links of QKPC are closely connected and form a complete educational loop, returning education to the essential mission of engineering education, solving real problems and cultivating high-quality engineering talent [6].

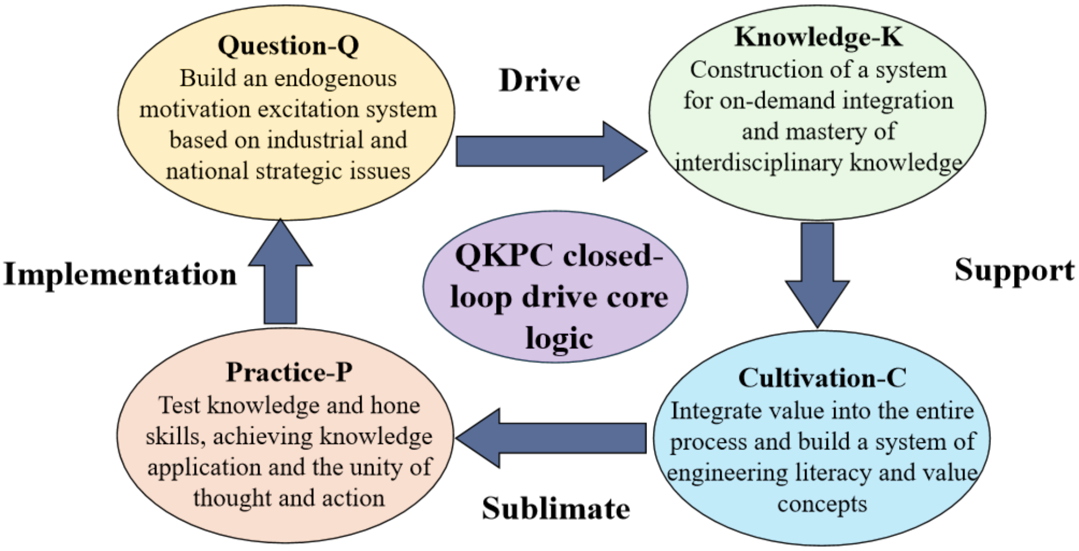

Figure 1. The new educational philosophy is driven by QKPC.

2.2. Major problems addressed by the QKPC talent cultivation model

2.2.1. Bridging the knowledge–engineering demand gap

A common phenomenon in current engineering education is that students passively receive knowledge and lack intrinsic motivation for innovation. The theoretical knowledge acquired in traditional classrooms is often confined to fundamental theories and isolated skills within a single major, making it difficult to effectively respond to the interdisciplinary knowledge demands posed by complex engineering problems in industry. Students also find it challenging to integrate and apply knowledge from different disciplines in practical innovation. In many cases, they lack not only an awareness of engineering problems and the ability to identify them, but also effective pathways for transforming theoretical knowledge into practical innovation. Consequently, their capacity to solve real-world problems remains weak, and their innovative thinking and comprehensive literacy fail to meet the demands of national strategies and industrial development for interdisciplinary engineering talent, thereby seriously constraining the quality and developmental path of such talent cultivation.

By establishing an engineering-oriented and problem-solving learning mechanism, the QKPC talent cultivation model addresses the disconnection between knowledge and engineering demands, as well as the gap between skills and practical application, in traditional practical teaching. Driven by real engineering problems, the model breaks through the administrative boundaries and knowledge barriers among materials science, mechanics, mechanical engineering, computer science, artificial intelligence, and other related disciplines. It integrates theoretical knowledge and technical skills from different disciplines into the entire process of practical teaching, guides students to build a systematic interdisciplinary knowledge system, and cultivates their engineering thinking and comprehensive application ability. This realizes the deep integration of knowledge, learning and practical innovation. At the same time, it encourages students to proactively integrate and apply multi-disciplinary knowledge to solve real problems in additive manufacturing topology optimization design, stimulates learning motivation, and enables students to acquire knowledge that is sufficient, applicable, and effectively deployable [7].

2.2.2. Overcoming barriers to interdisciplinary integration and practice

Influenced by traditional educational models and disciplinary structures, universities have long suffered from excessive specialization, insufficient interdisciplinary integration, and dispersed educational resources in talent cultivation. These conditions have led not only to fragmented knowledge structures, insufficient interdisciplinary thinking, and a disconnect between theoretical learning and industrial needs, but also to a mismatch between students' practical innovation capacity and comprehensive competence and the requirements of national strategies and industrial development for interdisciplinary engineering talent. At the same time, they have resulted in inefficient use of teaching and research resources, inadequate support for students' interdisciplinary practice, and unsatisfactory outcomes in practice-based education. These issues have become major bottlenecks that restrict the cultivation of innovative interdisciplinary talent and hinder improvements in the quality of practical teaching.

To address these problems, the QKPC talent cultivation model, centered on the core objective of practice-based education, proposes a collaborative educational mechanism characterized by interdisciplinary integration, cross-platform coordination, and multi-objective alignment [8]. In terms of interdisciplinary integration, the model reconstructs the talent cultivation system and curriculum matrix by overcoming the overly narrow knowledge boundaries imposed by traditional disciplinary divisions and by promoting substantive disciplinary convergence. In alignment with major national strategic needs and complex engineering problems in industry, it integrates the core knowledge systems of related disciplines, establishes modular interdisciplinary courses, and promotes deep interaction and organic integration among teaching contents from different fields. In terms of cross-platform integration, it establishes an internal coordination mechanism for university resources, breaks through departmental and disciplinary resource restrictions, and systematically integrates laboratories, research platforms, enterprise bases, and other resources to realize shared use. In terms of multi-objective guidance, with the cultivation of interdisciplinary and innovative engineering talent as the core, it simultaneously takes into account knowledge transmission, skill training, innovation cultivation, and value shaping, thereby promoting the organic integration of resource coordination with practice-based education, scientific innovation, and achievement transformation, and forming a synergistic educational landscape.

2.2.3. Overcoming the sustainability deficit in traditional practical teaching

Most practical teaching contents suffer from one-off and fragmented operation. Due to the lack of a systematic mechanism that supports sustained development, patriotic education and comprehensive quality cultivation cannot be effectively embedded throughout the entire practical teaching process, making it difficult to achieve the unity of moral education and competence development. The QKPC talent cultivation model addresses the tendency in practical teaching to emphasize knowledge while neglecting quality cultivation. It integrates value shaping into the entire practical process and establishes a replicable and scalable educational model. This model cultivates interdisciplinary and innovative engineering talent who not only possess solid engineering and technical foundations and the ability to solve interdisciplinary complex engineering problems, but also demonstrate rigorous engineering ethics, persistent craftsmanship, and a strong sense of social responsibility. In doing so, it precisely meets the core talent demands of China's strategic emerging industries, such as high-end equipment manufacturing and additive manufacturing, and fully responds to the national strategy of building a manufacturing powerhouse and its demand for high-quality engineering talent [9].

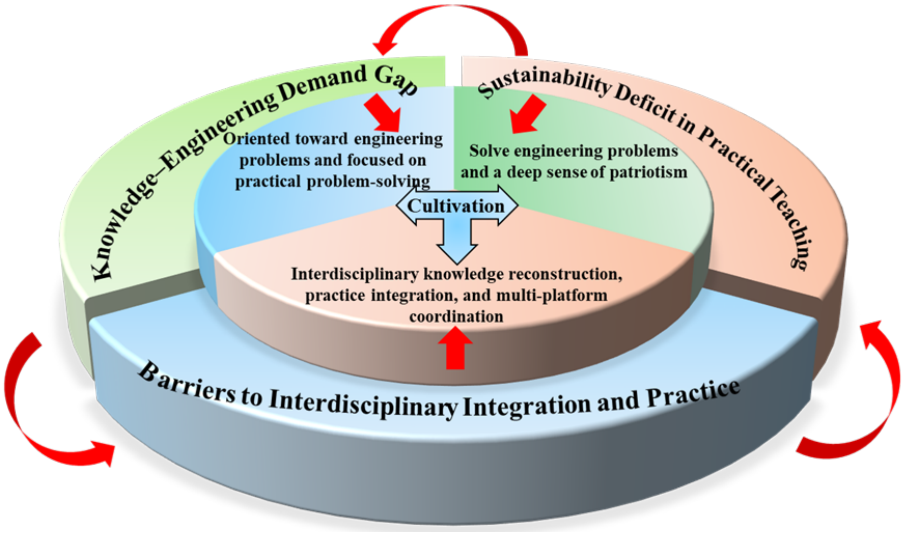

Figure 2. Major problems addressed by the QKPC talent cultivation model.

3. Construction of the new educational model and reform content

3.1. Building demonstration carriers for practice-based education driven by QKPC

Focusing on real engineering pain points in the field of additive manufacturing design, this reform develops a hierarchical and modular practical project system that transforms complex engineering problems into training content suitable for undergraduates. It guides students to move from passive problem solving to active problem identification and resolution, thereby improving their core competence in solving interdisciplinary complex engineering problems. It also continues to improve intelligent additive manufacturing teaching modules through in-depth exploration and upgrading from four dimensions, namely technical learning, achievement transformation, environmental impact, and application effectiveness. Student teams are supported in presenting project outcomes in national and international disciplinary competitions as well as innovation and entrepreneurship contests, enabling the project system to evolve into an integrated educational carrier that combines education, scientific research, and social application. More importantly, this system should be reflected in its typicality as an educational case, in the effectiveness of transforming students' independent scientific and technological achievements into teaching resources, and in its demonstrative practical value. In this way, it may become a demonstration field and model workshop that vividly interprets the QKPC-driven educational philosophy.

3.2. Educational mechanisms for interdisciplinary knowledge reconstruction

By breaking down the boundaries among materials science, mechanics, mechanical engineering, computer science, and artificial intelligence, and taking additive manufacturing topology optimization design as an example, this reform adopts industry-oriented engineering problems as the central guide for teaching and learning. With the support of artificial intelligence and related technologies, it constructs an interdisciplinary knowledge graph and establishes a collaborative educational mechanism that deeply integrates knowledge and practice. In this way, systematic integration and application of multi-disciplinary knowledge can be achieved, thereby promoting the formation of an interdisciplinary system. Supported by the coordinated efforts of interdisciplinary collaboration, cross-platform, and multi-objective guidance, innovation and humanistic care gradually become part of the team culture [10].

3.3. Verifying model transferability and developing an educational approach

The QKPC-driven educational model is oriented toward the core objectives of replicability, transferability, and scalability. Based on practical projects, it carries out iterative optimization, breaks through the limitations of traditional talent cultivation models by single objectives and fragmented implementation, and constructs a new paradigm of engineering education featuring full-process coordination. This study closely aligns with the national requirements for engineering education reform by integrating four core qualities, namely engineering ethics, innovative thinking, craftsmanship, and social responsibility, into the entire chain of practical teaching. It promotes the deep coordination of three major cultivation goals, namely skill training, innovation development, and value shaping, and aims to cultivate interdisciplinary and innovative engineering talent in line with national strategies and industrial demands. Relying on demonstration project carriers and educational support mechanisms, this model verifies its transferability through student-led practical projects, confirms the replicability and scalability of the project-based educational system, and ultimately refines a sustainable educational approach adaptable to multiple scenarios, thereby providing a standardized and widely applicable educational paradigm for similar institutions.

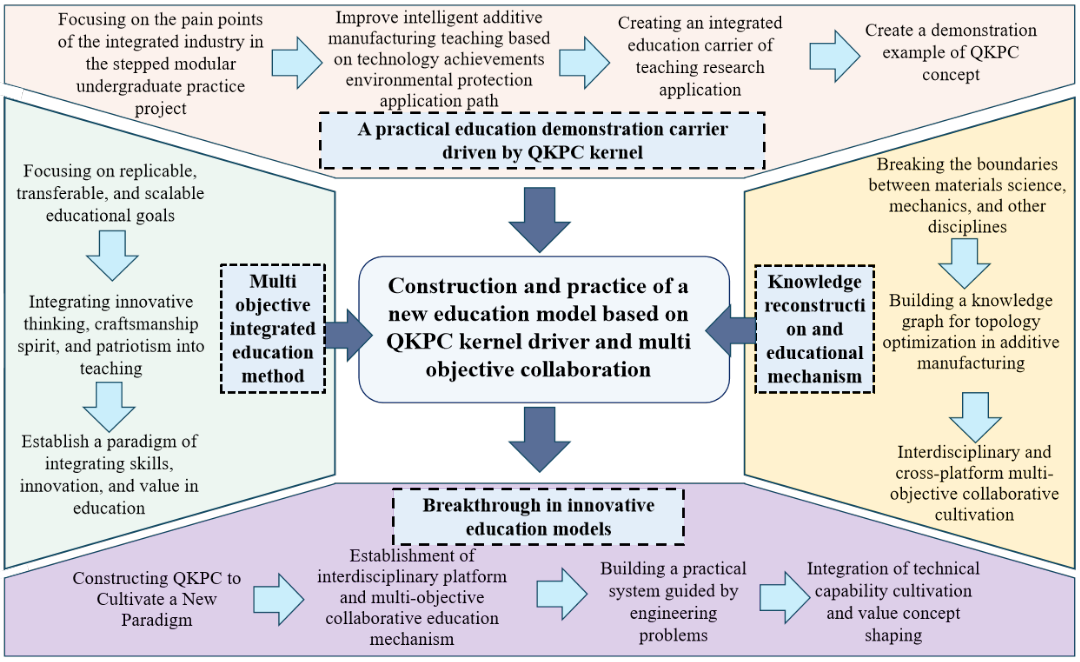

Figure 3. Construction and practice of the new QKPC-driven educational model.

4. Practice of the QKPC educational model

Oriented toward the goals of replicability and scalability, the QKPC model has already been implemented extensively and in multiple dimensions.

4.1. Internal implementation to strengthen the educational foundation

The model has achieved deep penetration and comprehensive implementation within the university. The QKPC-driven educational system and interdisciplinary practical teaching content constructed in this study have been gradually integrated into the full practical teaching process of core engineering majors, including materials science, mechanics, mechanical design, computer science and technology and so on, realizing full coverage from basic training to comprehensive design. Two undergraduate general education courses in cultural quality have been offered within the university. In these courses, the traditional mode of theoretical indoctrination has been broken, and hands-on projects such as intelligent structural deformation verification and topology optimization of lightweight components have been introduced into the classroom. A talent cultivation model integrating classroom teaching with engineering field practice has been adopted, in which real industrial needs and practical engineering problems serve as the central orientation, enabling students to transform acquired knowledge into practical competence.

Through the combination of classroom teaching and experimental practice, it is ensured that students acquire knowledge that truly serves the needs of industry. In classroom teaching, core concepts are taught through the analysis of real engineering scenarios, targeted learning is conducted to address students' weak knowledge areas, and hands-on operational ability is strengthened simultaneously. In field-based training, students are organized to visit the production of partner enterprises, and are guided to systematically transform theoretical knowledge into engineering practical competence in the process of solving real engineering problems. In this way, their core literacy in addressing complex engineering problems is comprehensively enhanced, and high-quality engineering talent capable of meeting industrial development needs is effectively cultivated. Students are thus enabled to convert what they have learned into actual engineering experience through solving real problems and to comprehensively improve their ability to tackle complex engineering challenges.

4.2. University-enterprise collaboration to meet industrial demands

Long-term partnerships have been established with leading enterprises in the aerospace and high-end equipment sectors. Research achievements developed through scientific projects, including additive manufacturing, topology optimization design solutions and performance testing systems, have been applied to the trial production of lightweight components and intelligent functional parts in manufacturing processes, helping enterprises overcome technical problems. At the same time, enterprise projects and industrial needs have been brought back into the university's practical teaching system. Students have been organized to visit facilities such as the additive manufacturing units of the Fifth Academy of Aerospace and Land Space, while researchers from institutes have been invited to serve as practice mentors. This has promoted the deep integration of enterprise practice resources with university teaching resources, enabled a close connection between teaching practice and industrial application, and enabled students to refine their engineering practical competence by solving real industrial problems, thereby cultivating interdisciplinary engineering talent suited to industrial development and earning high recognition from partner enterprises.

During the teaching practice stage, course content has been further deepened through strategic cooperation with aerospace research institutes, thereby establishing a core practical teaching pathway oriented toward engineering problems. Under the guidance of the mentor team, students have directly engaged with the actual needs of aerospace missions. For example, students were guided to design ultra-lightweight lattice skin structures and to iteratively improve structural designs through a closed loop of theoretical modeling, scheme demonstration, and experimental testing, ultimately producing new structures applicable to multiple fields. Students were also led to conduct systematic innovation research on hybrid unit-cell structure design, successfully applying for and obtaining approval for scientific research projects. Throughout the teaching process, engineering demands served as the core driving force, while project-based teaching functioned as the carrier through which students systematically mastered interdisciplinary theories and technologies, such as additive manufacturing process optimization and AI-assisted topology optimization design. In collaboration with aerospace research institutes and enterprises, a university-enterprise collaborative education platform was established to promote students' deep participation throughout the entire process of product conceptual design, iterative optimization, production trial, and performance validation, thus realizing seamless integration between classroom teaching and industrial practice. At the same time, value guidance centered on serving the nation through science and technology, together with patriotic dedication, was embedded throughout the entire project cycle, cultivating students' sense of national commitment through industrial development. Ultimately, the core products developed within the project successfully passed special evaluation and validation by authoritative institutions and application units, and were successfully applied in multiple fields. Through this educational approach, students not only achieved the precise delivery of project indicators at the technical level but also deeply internalized the aerospace spirit of striving for excellence at the spiritual level, thereby accomplishing a transformation in value orientation from the acquisition of individual skills to a sense of mission devoted to the modernization of national defense.

4.3. Consolidating educational outcomes and expanding demonstration impact

The model has achieved experience sharing and demonstrated leadership across institutions. Relying on practical outcomes such as student innovation training projects and disciplinary competition works guided by this program, the team has actively participated in national and provincial engineering education competitions and teaching reform exchange activities, allowing the educational outcomes and practical experience of the project to gain wide attention and recognition from competition judges, industry experts, and peer universities. Design models generated through the courses have been directly transformed into innovation competition projects within the university, guiding students to participate in multiple innovation training projects and scientific research innovation projects, and to obtain scholarships and other honors. At the same time, through teaching reform exchange meetings, invited lectures, and the establishment of inter-university teaching and research cooperation mechanisms, the team has shared with many universities inside and outside the province the construction logic, implementation pathways, and practical effectiveness of the QKPC model, thereby providing targeted guidance and support for peer institutions in building interdisciplinary practical education systems and carrying out engineering education reform.

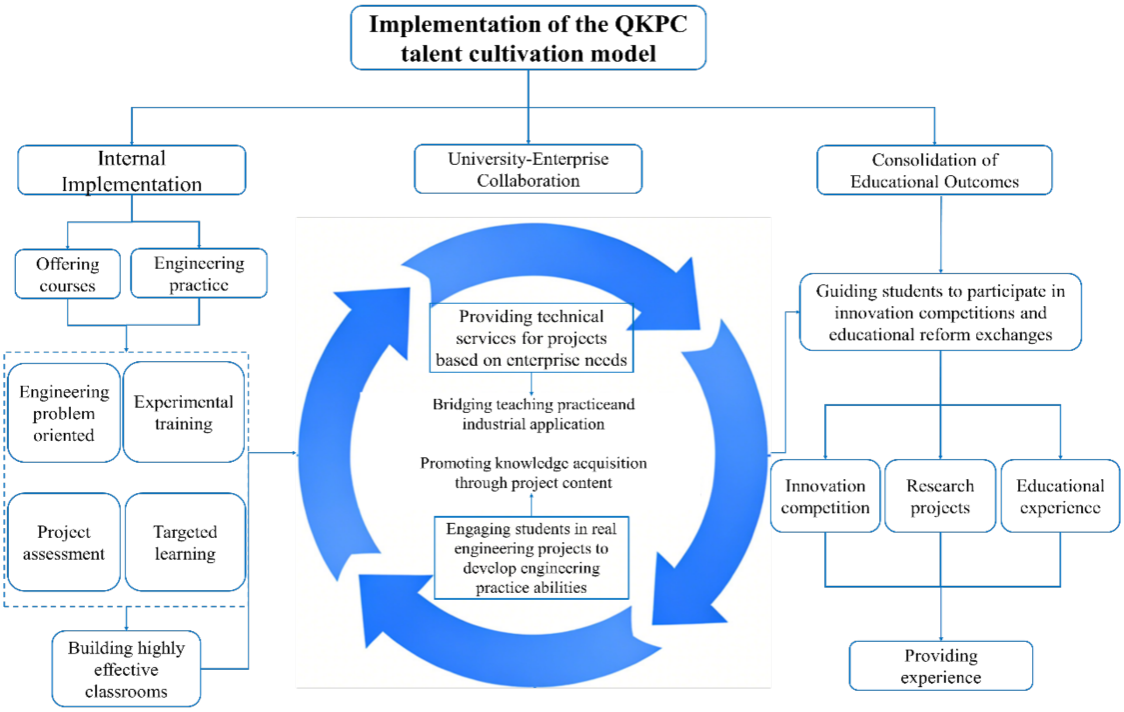

Figure 4. Dissemination pathways of the new educational model.

5. Conclusion

At this crucial stage of advancing the cultivating new quality productive forces, this teaching reform model will closely align with the strategic deployment of national high-level talent cultivation reform and achieve higher-level iterative upgrading and wider dissemination under policy guidance. In terms of model development, it will adhere to the core requirements of system reconstruction, process reengineering, capability reshaping, and evaluation rebuilding, further strengthening both the depth and breadth of interdisciplinary integration. Industrial demands in fields such as artificial intelligence and equipment manufacturing into the QKPC educational closed loop, and promote the alignment of curriculum systems with real enterprise needs and major national engineering missions. In this way, students may develop the ability to solve complex engineering problems through course practice and respond to the talent cultivation orientation of patriotism, professional dedication, and outstanding technological innovation. Through the continuous optimization of the multi-objective educational system, engineering ethics, craftsmanship, and social responsibility will be integrated throughout the whole process, thereby cultivating interdisciplinary engineering talent with both moral integrity and professional competence, as well as the ability to integrate knowledge with action. By adapting to regional industrial needs and exploring industry education integration models suited to local conditions, the reform will also contribute to the improvement of regional innovation systems. The QKPC educational model will become a core vehicle for the cultivation of interdisciplinary talent, provide talent support for achieving high-level scientific and technological self-reliance and building a world-leading manufacturing power, and contribute continuous strength from engineering education into modernization.

Author contributions

Tao ran: Writing – review & editing, Writing – original draft, Methodology, Investigation;
Ying-tao Zhao: Writing – review &editing;
Ming-ji Chen: Methodology, Investigation;
Hua-dong Yang: Resources, Investigation;
Meng Yu-huan: Resources, Investigation.

Disclosure statement

The author declares no conflict of interest.

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