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Comprehensive Reform Exploration for Innovative Talent Cultivation of Biomedical Engineering

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Abstract: In response to the issues of weak practical teaching, insufficient cultivation of innovation ability, and the problem of disconnection between knowledge impartation and value guidance that have emerged in the process of cultivating undergraduate talents in biomedical engineering, we have explored comprehensive reforms in innovative talent cultivation in the context of comprehensively deepening the comprehensive reform of education in our university. Focusing on the core characteristics of medical-engineering integration, we have integrated resources from multiple parties including "universities, enterprises, hospitals, supervision/regulatory agencies, and research institutions", built a diversified education platform, and deeply integrated ideological and political education, industrial project practice, and professional teaching through reconstructing a modularized curriculum system, promoting interdisciplinary mentor groups, implementing science-education integration, and project-based scientific research training. Practice has shown that the comprehensive reforms have effectively addressed issues such as prominent disciplinary barriers, weak practical education, and insufficient cultivation of innovation ability in traditional training models. They have significantly improved students' medical-engineering composite literacy, engineering practice ability, and innovation and entrepreneurship level, and have cultivated a large number of high-quality innovative interdisciplinary talents to the medical device industry.

1. Introduction

Medical devices represent a strategic emerging industry that safeguards national health and public health security, and also constitute a core priority sector for China’s high end manufacturing drive. Guided by national strategic initiatives including the *14th Five Year Plan for the Development of the Medical Equipment Industry*, the medical device industry is striving to break bottlenecks in core technologies, advance domestic substitution of high end equipment, and build an independent and controllable industrial supply chain. As one of the core disciplines at the intersection of medicine and engineering, biomedical engineering (BME) serves as a cornerstone force underpinning the high quality development of the medical device industry and the implementation of national strategies [1-4].

Nowadays, China's medical device industry still faces challenges including reliance on imports for high end equipment, dependence on foreign suppliers for core components, and insufficient innovation in high end intelligent medical equipment. These have become bottlenecks restricting the development of the healthcare industry. As an interdisciplinary discipline, biomedical engineering integrates knowledge from medicine, engineering, electronic information, materials science and other fields. It precisely aligns with the strategic priorities of the industry, focusing on key areas such as medical imaging equipment, minimally invasive medical devices, intelligent medical equipment, and biomedical materials. It provides core technical support for the technological iteration and product upgrading of domestically produced medical devices [5-8].

2. Current Situation of Undergraduate Talent Cultivation

Represented by the United States and Europe, the overseas undergraduate talent-training system for BME is relatively mature and well-established, serving as a global benchmark for BME undergraduate education. Its four-year undergraduate program features a high degree of standardization and refinement. Top-tier universities break down disciplinary barriers and jointly build undergraduate education platforms in collaboration with engineering schools, medical schools, affiliated hospitals and leading medical enterprises. The curriculum abandons fragmented subject-based teaching. Core medical courses such as engineering technology, human physiology and anatomy are offered as early as the freshman year. Three core modules, namely clinical requirements, industrial regulations and research ethics, run through the whole program. Rigorous industry-oriented courses, including medical device design controls, medical device quality and risk analysis, and medical device prototyping, are compulsory, enabling seamless alignment between knowledge systems and industrial standards.

China has a large-scale undergraduate education in BME. More than 140 universities nationwide offer the four-year undergraduate program, forming a hierarchical education layout. Centred on cultivating interdisciplinary and application-oriented engineering and technical talents, the training goal is to meet the demand for entry-level positions in the medical device industry. The undergraduate curriculum generally adopts a three-tier structure: general foundational courses, introductory medical courses, and core engineering courses. Practical teaching mainly consists of on-campus laboratory experiments, simulation training, short-term enterprise internships, and senior-year graduation practice. Most universities lack regular clinical collaboration and hands-on training on real-world industrial projects. In terms of employment outcomes, undergraduate graduates show limited post-matching fitness. They are mostly engaged in equipment testing, technical support, equipment maintenance, sales and basic-process positions, while very few can access high-end core R&D positions [9,10].

3. Problems in the Existing Talent Training Mode

Taking the BME program at the University of Shanghai for Science and Technology, where the author is affiliated, as an example, this paper illustrates the existing problems in the undergraduate talent-training model.

The BME program at our university has a long-standing educational heritage and ranks among the university's most distinctive and competitive engineering disciplines. Approved as a pilot program under the Ministry of Education's Outstanding Engineer Education and Training Program in 2013, it was selected for the first batch of national first-class undergraduate majors under the "Double Ten-Thousand Plan" in 2019. This milestone marked that its education quality, teaching standard and talent-training capacity had reached the domestic top-tier level. Leveraging the geographical and industrial advantages of Shanghai as a highland for the medical device industry, the program is deeply rooted in local industrial resources. It closely responds to the demands of the whole industrial chain covering R&D, manufacturing and innovation of regional medical devices. A large number of high-caliber engineering-technical and innovative talents have been cultivated for the Yangtze River Delta and even the whole country's medical device sector, with continuously growing industry recognition and social influence.

With the rapid iteration of the digital economy and artificial intelligence technologies, the field of BME is undergoing comprehensive transformation. Emerging directions such as intelligent healthcare and precision medicine are rising rapidly, bringing continuous innovation to the industry's development model and technical requirements. Driven by this wave of era development and the impact of intelligent technologies, the shortcomings of the program's traditional education mode and training system have gradually become prominent, which are mainly reflected as follows,

3.1 Insufficient Practical Teaching & Lack of Hands-on Engineering Skills

The medical device industry is a technology-intensive high-end sector. The whole workflow including product R&D, assembly and commissioning, clinical adaptation, and quality control imposes stringent and high requirements on practitioners' hands-on operation, engineering implementation and problem-solving capabilities. Enterprises attach great importance to students' experience in real-world projects during recruitment. In contrast, under the conventional teaching mode, the overall curriculum lays heavy emphasis on theoretical lectures while undervaluing hands-on training, with an obviously low proportion of class hours allocated to practical teaching. Most existing laboratory activities are limited to textbook-supported confirmatory basic experiments with fixed procedures and mechanical operations, which merely serve to verify theoretical principles from textbooks. There is a shortage of comprehensive training and innovative R&D-oriented practical projects that simulate real-world industrial scenarios. Students rarely get access to authentic enterprise engineering tasks such as complete medical device commissioning and fault troubleshooting during their studies. Deprived of experience across a full engineering workflow, they fail to effectively translate theoretical knowledge into practical skills, resulting in a notable disconnection between academic learning and industrial application.

3.2 Inadequate Innovation Cultivation & Insufficient Research Literacy

Medical devices represent an interdisciplinary field integrating biomedicine, mechanics, electronics, materials, software and other disciplines. Characterized by rapid industrial iteration and continuously-updated clinical demands, the market is in urgent need of compound professionals equipped with multidisciplinary knowledge, practical capabilities and strong innovative literacy. Whether it involves the R&D of novel diagnosis-and-treatment equipment, performance optimization of medical devices, or modification of customized medical appliances adapted for different clinical departments, practitioners are required to carry out innovative design and technical research targeting real-world clinical pain points.

Nevertheless, the traditional teaching mode and process at the current stage lack step-by-step and systematic training for guiding innovative thinking, as well as full-cycle innovative practice covering scheme conception, prototype fabrication, testing and improvement. Students cannot get sufficient training to cultivate their innovative awareness and hands-on R&D capabilities for independently identifying demands, conducting design modification and overcoming technical bottlenecks. Restricted by textbook-based knowledge frameworks, they show weak capacity for independent innovation and tackling technical challenges. Their overall competence fails to meet the recruitment and employment standards for interdisciplinary innovative talents amid the rapid development of the medical device industry.

3.3 Weak Craftsman Spirit Inheritance & Value Guidance

Within the talent-training system for medical-device engineering majors, the craftsman spirit serves as the core underpinning for the long-term industrial development and the development of domestic high-end medical equipment, and constitutes an essential quality for practitioners. Since medical devices are directly related to patients' life and health, no negligence is permissible. Craftsman qualities such as rigorous attention to detail, pursuit of excellence, and commitment to quality bottom-lines are particularly critical.

Nevertheless, the traditional teaching mode shows obvious orientation bias. Teaching activities lay excessive emphasis on hard-skill instruction concerning performance parameters and technical indicators, and one-sidedly guide students to pursue parameter improvement, while weakening teaching and training on reliability design, including long-term stability, safety and durability of devices. Students are not fully immersed in the zero-defect quality culture of the industry and fail to establish a solid sense of responsibility for strict whole-process quality control. In design and R&D, they often deviate from real-world patient usage scenarios and lack people-oriented R&D thinking centred on patient safety and comfort.

This dichotomy, which overemphasizes technical performance while neglecting humanistic care and quality bottom-lines, prevents the integration of technical rationality and humanistic values. It becomes difficult to cultivate high-caliber talents with rigorous craftsmanship and patient-centred awareness, and greatly hinders the development of a high-quality engineering workforce capable of boosting the breakthrough and upgrading of domestic high-end medical equipment with both exquisite craftsmanship and original craftsman aspirations.

4. Exploration of Comprehensive Reform

Targeting prominent pain points in traditional talent training, such as the disconnection between theory and practice, insufficient interdisciplinary integration, and poor industrial adaptability, our university advances comprehensive specialty-wide reform in an all-round manner. By reconstructing the talent-training system, innovating education modes, deepening the integration of industry and education, and optimizing the evaluation mechanism, the university has explored a distinctive development path adapted to engineering talent training in the new era and responsive to actual industrial demands. It provides solid talent and technical support for the high-quality development of the local healthcare industry.

This comprehensive specialty reform adheres to demand-oriented, problem-oriented and effect-oriented principles. Focusing on three core dimensions: interdisciplinary integration, practice-driven education, and industry-education collaboration, it breaks the barriers of traditional single-discipline education. Based on the interdisciplinary characteristics of the discipline, a training system for top-notch interdisciplinary and application-oriented talents is constructed. It promotes the in-depth integration of natural sciences and engineering technologies, as well as engineering technologies and biomedicine, so as to comprehensively improve the quality of talent training and the core disciplinary competitiveness.

4.1 Reconstruction of the Curriculum System

Curriculum system reconstruction constitutes the core foundation of comprehensive specialty-level reform. Selected via the national college entrance examination, students are admitted to our university under the intelligent manufacturing broad-category program for broad-category talent training. They will stream into the BME major through specialty diversion in the second semester of their first academic year. This major offers three directions: biomedical electronic engineering (abbreviated as BMEE), intelligent medical device engineering (abbreviated as IMDE), and medical device regulatory science (abbreviated as MDRS). Accordingly, further direction-specific diversion is implemented at the beginning of the second academic year, after which talent cultivation is carried out separately for the three directions (see Table 1).

Table 1: The three directions of BME major

Direction	General Description	Main Curriculums
biomedical electronic engineering (BMEE)	Combining electronic technology, signal-processing technology, computer and information technology, it detects and processes human physiological signals and performs imaging of human tissues for accurate disease diagnosis and precise treatment.	biomedical electronics, signals and systems, digital signal processing, biomedical sensing technology and applications, embedded operating systems, artificial intelligence and machine learning, etc.
intelligent medical device engineering (IMDE)	It adopts knowledge of optics, mechanics, electronics and computing to conduct principle analysis and system design for intelligent and precision medical devices, such as surgical robots and navigation systems, human-machine replacement devices, and in-vitro diagnostic analysis technologies.	medical device system design, biomedical sensing and detection, microcomputer principles and applications, principles of automatic control, fundamentals of mechanics and mechanical design, computer-aided design for medical devices, etc.
medical device regulatory science (MDRS)	For both active and passive medical device products, technical-level performance testing, supervision and safety evaluation are carried out on the safety, effectiveness and reliability of medical devices in accordance with national standards, laws and regulations, including electromechanical performance, safety specifications, electromagnetic compatibility, etc.	supervision and management of medical devices, biomedical engineering materials, medical electrical safety technology, medical electromagnetic compatibility technology, active medical devices and test and evaluation, testing technology for passive medical devices, etc.

Abandoning the traditional silo-style separate-subject teaching model, the major optimizes its curriculum structure centring on the three directions and builds a hierarchical, progressive, interdisciplinary and integrated curriculum system. At the general education level, teaching in mathematics-physics fundamentals and life-science general knowledge is strengthened to consolidate students' foundation for interdisciplinary learning. At the professional core level, distinctive courses are offered for each of the three directions to make up for knowledge gaps required by industry demands. Meanwhile, keeping pace with cutting-edge industrial developments, teaching contents are dynamically updated. Emerging technologies such as artificial intelligence, big data and precision medicine are integrated into classroom instruction, so that curriculum contents keep abreast of the iteration of industrial technologies. Figure 1 illustrates the competency achievement chain of the curriculum systems for the three directions after the implementation of comprehensive specialty reform.

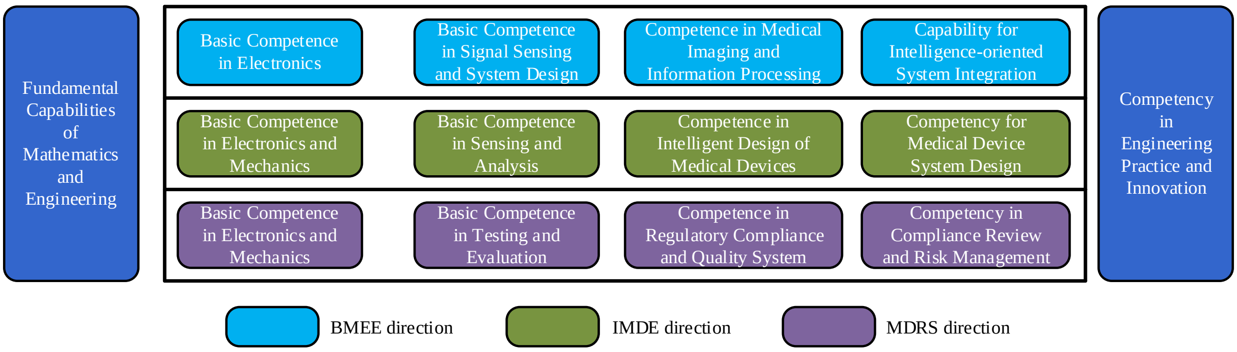

Figure 1: Competency achievement linkage diagram of BME curriculum system

4.2 Faculty Team Building

Faculty team building constitutes the key support for reform implementation. To address the disciplinary limitations of on-campus faculty alone, the college has established an interdisciplinary and cross-institutional “cross-boundary supervisor group” and constructed a diversified dual-qualified faculty system. On the one hand, it integrates on-campus faculty resources from engineering, biology, medicine, computer science and other disciplines to break down disciplinary barriers in talent cultivation. On the other hand, industrial supervisors are recruited from Grade-A tertiary hospitals and leading medical device enterprises. Clinicians, senior engineers and industrial technical experts are incorporated into the education team, forming a collaborative education pattern where on-campus supervisors consolidate theoretical foundations and industrial supervisors guide practical innovation. Over the past four years, the major has continuously optimized its faculty structure. Regular exchanges between university and enterprise faculty, teaching seminars and joint lesson-preparation activities have been carried out to fully integrate cutting-edge industrial technologies, real-world clinical problems and industrial project requirements into the whole-process teaching. Meanwhile, relying on the university-wide ideological and political education system, teachers are guided to integrate the spirit of scientists, professional ethics and craftsmanship spirit into daily teaching. A high-level faculty team with both professional competence and education capacity is built, providing core guarantee for interdisciplinary talent cultivation.

4.3 Deep Integration of Science, Education and Industry

Deep integration of science, education and industry represents the core feature of this comprehensive reform. Leveraging the strengths of Shanghai’s medical device industry, the college adheres to the reform philosophy of “research feeding teaching and industry empowering talent cultivation”, and has built multi-level practical innovation platforms to actively reverse the traditional talent-training mode that “emphasizes theory while neglecting practice”. In terms of on-campus platform development, supported by the professional experimental teaching centre, the college improves practical training venues for medical device design, prototype testing and biomedical measurement, and sets up open-access innovation laboratories to support students in independently conducting scientific and technological innovation projects, prototype development and technical optimization. For off-campus practical training expansion, university-enterprise and university-hospital cooperation is continuously deepened. Multiple new practical education bases have been added, and joint training platforms are co-established with medical device enterprises and medical institutions. This enables students to be deeply involved in the whole process of real-world clinical demands and industrial project research-and-development. Students participate in the full workflow ranging from algorithm design and structural development to prototype testing and result iteration, striving to apply what they have learned and transform classroom knowledge into practical capabilities.

4.4 Project-based Talent Cultivation

BME is a typical medicine-engineering interdisciplinary discipline. Traditional classroom-based theoretical teaching has prominent pain points such as disconnection between theories and clinical demands, inadequate engineering practical capabilities, and insufficient comprehensive innovative literacy. In response to the requirements of emerging medical education and emerging engineering education initiatives, the implementation of a full-process project-based talent cultivation mode can break down educational barriers among classrooms, laboratories, clinical hospitals and medical device enterprises. It constructs a closed-loop talent-cultivation system centred on real-world medical projects with joint guidance by both medical and engineering supervisors, which caters to the talent demands of the industry for posts including medical device R&D and clinical engineering.

This cultivation mode takes real-world clinical pain points and industrial rigid demands as project sources. Students are organized to go deep into clinical departments of Grade-A tertiary hospitals to observe diagnosis-and-treatment workflows and collect front-line clinical problems. Project teams are formed focusing on directions such as medical robots, portable diagnosis-and-treatment equipment, optimization of medical imaging algorithms, and rehabilitation assistive devices. It covers the complete R&D chain from demand investigation, scheme design, simulation modeling, prototype development, clinical testing, achievement optimization to final project defense. Fragmented theoretical knowledge including human anatomy, physiological signal detection, mechanical design, embedded development and artificial intelligence algorithms is integrated into the practice of complete engineering projects.

A university-enterprise-hospital joint supervisor system is implemented throughout the cultivation process. University engineering faculty provide technical guidance, clinicians oversee the compliance of medical requirements, and enterprise engineers align projects with industrial standards and commercialization requirements, so as to remedy the deficiencies brought by talent training relying solely on on-campus faculty. Meanwhile, three types of project carriers are provided, namely discipline-oriented competitions, research projects and graduation design, to realize step-wise cultivation consisting of basic practical-training projects for lower-grade students, comprehensive R&D projects for upper-grade students, and industrial-oriented graduation-design projects.

5. Reform Outcomes

Relying on the strengths of Shanghai Class-III Peak Discipline and the National First-class Undergraduate Major construction, this major focuses on the bottlenecks in medicine-engineering integration and deepens the comprehensive reform of five-party collaborative talent cultivation among universities, enterprises, hospitals, regulatory authorities and research institutes. A hierarchical innovative talent-cultivation system has been established. Remarkable outcomes have been achieved in terms of teaching quality, scientific and technological innovation capacity, and talent output. The education achievements highlight the major’s distinctive features and its adaptability to industry needs.

The talent-cultivation system has been continuously optimized. The major has reconstructed a modular curriculum system, with practical credits accounting for 33% of total credits. It has obtained one national first-class course (virtual simulation), two Shanghai Municipal first-class courses and six Shanghai municipal key courses, and published 12 textbooks. In teaching practice, basic training in mechanics, electronics and programming capabilities is strengthened, and the project-based teaching mode is implemented to break down barriers between theoretical teaching and industrial practice, effectively improving students' ability to solve complex engineering problems. Meanwhile, the incentive system for innovation and entrepreneurship has been improved. Supported by the Shanghai-level Experimental Teaching Demonstration Center and the Modern Industry Institute for Medicine-Engineering Integration, all-round practical education carriers have been established. The teaching reform achievement has won the first-class prize of Shanghai municipal teaching achievement award. The talent-cultivation mechanism has become increasingly mature. In 2023, the major was also awarded the first-class prize for excellent major construction of our university.

Students have achieved fruitful outcomes in scientific and technological innovation. In recent years, students' performance in science and innovation competitions has been greatly enhanced. They have obtained outstanding awards in successive sessions of the China International "Internet+" Innovation and Entrepreneurship Competition, the China International College Students' Innovation Competition, and the National Biomedical Engineering Innovation Design Competition for University Students.

The quality of talent output has been steadily improved. Thanks to the systematic reform, students' core competitiveness has been significantly enhanced. The average further-study rate over the past five years exceeds 50%, and the domestic and overseas further-study rates exceeded 60% in 2023 and 2026 respectively. The average growth rate of social-insurance contribution base for Shanghai 2019-cohort graduates stood at 19.4%, while that of BME graduates from our university reached 30.3%, ranking first among all majors of the university.

6. Conclusions

In 2026, our university further deepened the comprehensive reform of talent cultivation, and listed medical devices as the first among the six key service fields. It has reshaped the development landscape of the BME major across all dimensions, including disciplinary positioning, talent cultivation, platform resources, industry-education collaboration, employment and further study, as well as scientific research and innovation. The major's core status as the university's central pillar for medicine-engineering integration has been consolidated in an all-round manner.

At the level of top-level disciplinary positioning, the reform layout prioritizing the development of the medical device sector has to some extent clarified the construction priority of this major. In terms of the innovation of talent-cultivation system, supported by the special comprehensive-reform fund, a large number of project-based courses featuring real-world corporate R&D, registration and testing projects have been introduced. The five-party integrated talent-cultivation mechanism involving universities, enterprises, hospitals, regulatory authorities and research institutes has been implemented. The complete workflow of medical device product development, clinical verification and compliance registration is embedded into undergraduate teaching, so as to make up for the gaps in engineering practice for compound medicine-engineering talents and address the mismatch between university talent supply and industry job requirements. From the perspective of faculty and industry collaboration, the university has stepped up the recruitment of industrial supervisors specializing in medical device R&D, registration and clinical engineering, building a dual-qualified faculty team consisting of on-campus "academic supervisors" and "corporate engineering supervisors". In respect of employment, further study and major competitiveness, great efforts are made to substantially raise the major's industrial visibility and recognition, precisely matching the "talent orders" of the Yangtze River Delta medical device industry. It broadens graduates' access to R&D, quality control, registration and clinical engineering positions in leading enterprises such as

United Imaging, MicroPort, Siemens and Philips, and improves the employment rate and salary level within the high-end medical equipment sector.

The BME major will continue to deepen the iteration and upgrading of its talent-cultivation mode, consolidate interdisciplinary innovation and practical platforms, and improve the full-cycle guarantee mechanism for talent cultivation. It strives to foster compound medical-device talents who are proficient in engineering, familiar with clinical practice, committed to the mission and capable of innovation. Through continuously deepening comprehensive talent-cultivation reform, the major contributes to the breakthrough-driven development of China’s high-end medical equipment industry and lends disciplinary strength from higher education institutions to the Healthy China Initiative.

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