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A Study on the Implementation Pathways for Integrating the Smart Manufacturing Engineering Major with Entrepreneurship

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Abstract: Against the backdrop of the in-depth implementation of the "Made in China 2025" strategy, the comprehensive advancement of new engineering disciplines, and the implementation of the 2026 "Implementation Guidelines for the 'AI+ Manufacturing' Special Action," the deep integration of innovation and entrepreneurship education with professional education in the field of intelligent manufacturing engineering represents a core direction for educational reform aimed at supporting the high-end, intelligent, and green transformation of the manufacturing sector. This paper systematically reviews the theoretical research findings and policy frameworks regarding the integration of innovation and entrepreneurship with professional education in the field of intelligent manufacturing from 2020 to 2026. By analyzing industry-education integration case studies from leading domestic institutions and incorporating the latest talent demand trends in the intelligent manufacturing sector, the paper explores implementation pathways, existing challenges, and optimization strategies for this integration. The study finds that while three mainstream models of integration have emerged in the field of smart manufacturing, common challenges persist, including conceptual disconnect, superficial course integration, ineffective school-enterprise collaboration mechanisms, and insufficient faculty capabilities. Reform must be systematically advanced across four dimensions: restructuring the curriculum system, improving school-enterprise collaboration mechanisms, strengthening the faculty, and establishing a diversified evaluation system. Ultimately, this will achieve the synergistic enhancement of students' professional and innovation-entrepreneurship competencies, thereby supplying the manufacturing sector with versatile innovative talent to support high-quality development.

Keywords: Smart Manufacturing; Innovation and Entrepreneurship; Curriculum System.

1. Introduction

Smart manufacturing is the core driving force behind the new round of technological revolution and a key strategy for China to build itself into a manufacturing powerhouse. The "14th Five-Year Plan for the Development of Smart Manufacturing" explicitly states [1] that by 2025, the majority of manufacturing enterprises above a certain scale will have achieved digitalization and networking, and leading enterprises in key industries will have begun to apply intelligent technologies; by 2035, digitalization and networking will be fully implemented, and leading enterprises will have basically achieved intelligent manufacturing. With the large-scale application of technologies such as artificial intelligence, the Industrial Internet, and digital twins, the scale of China's smart manufacturing industry continues to expand. By 2025, the total demand for talent in the industry is expected to reach 9 million people, with a talent shortage exceeding 4.5 million. Among these, the shortage of multidisciplinary talent—those possessing both professional technical skills and innovation and entrepreneurship capabilities—accounts for over 70% [2]. As the core discipline linking the smart manufacturing industry, the central challenge of educational reform in the Smart Manufacturing Engineering program is to address the industry's pain point of the disconnect between innovation and entrepreneurship education and professional education [3]. Since 2020, the Ministry of Education has continuously deepened the development of new engineering disciplines and the Action Plan for Improving the Quality and Excellence of Vocational Education. The newly revised "Vocational Education Law of the People's Republic of China" in 2022 explicitly calls for strengthening the deep integration of innovation and entrepreneurship education with professional education, The "Action Plan for Smart Manufacturing Talent Development (2025–2027)," jointly issued by the Ministry of Industry and Information Technology and the Ministry of Education in 2025, further designated the integration of innovation and entrepreneurship with specialized education as a core task in cultivating smart manufacturing talent [4–6]. Against this backdrop, this paper systematically examines the implementation pathways for integrating innovation and entrepreneurship with specialized education in the Smart Manufacturing Engineering program from three core dimensions—theoretical foundations, practical case studies, and alignment with industry demands—to provide theoretical references and practical insights for institutional reforms in talent cultivation.

2. The Theoretical Foundation of the Integration of Specialization and Innovation

Core Theoretical Foundations and Research Progress: The core guiding theories for integrating innovation and entrepreneurship into smart manufacturing primarily encompass three major frameworks: First, the "OBE (Outcome-Based Education) philosophy," which focuses on the professional competencies and innovation and entrepreneurship capabilities students ultimately achieve, using these outcomes to reverse-engineer talent development systems and ensure that educational activities align closely

with industry talent needs; Second, the "CDIO Engineering Education Model," which uses the full product lifecycle—from conception, design, and implementation to operation—as a vehicle to integrate innovation and entrepreneurship training into the entire engineering practice process, aligning with the engineering attributes and cross-disciplinary nature of smart manufacturing engineering programs; third, the "Triple Helix Theory," which emphasizes the collaborative interaction among universities, industry, and government, providing a theoretical framework for the integration of professional education and innovation/entrepreneurship as well as industry-education collaboration, and clarifying the boundaries of rights and responsibilities among multiple stakeholders. From 2020 to 2026, domestic academic research on the integration of specialized education and innovation and entrepreneurship in smart manufacturing has focused on four core directions: First, the innovation of educational philosophy. The academic community generally agrees that this integration is not a simple superposition of "specialized education plus innovation and entrepreneurship courses," but rather the incorporation of innovative thinking, entrepreneurial methods, and competency development into every stage of talent cultivation, achieving the unity of knowledge transmission, competency development, and value guidance; Second, the restructuring of the curriculum system, centered on the integrated development of "job roles, courses, competitions, certifications, and innovation," explores how to systematically incorporate innovation and entrepreneurship elements into core professional courses; third, the reform of teaching methods, focusing on researching the implementation pathways of project-based learning, case-based learning, and flipped classrooms in the integration of professional education and innovation and entrepreneurship; and fourth, the innovation of evaluation mechanisms, exploring how to construct a diversified evaluation system that balances professional competence with innovation and entrepreneurship capabilities, thereby avoiding the utilitarianization of education. At the policy level, the Ministry of Education's 2020 "Guidelines for New Engineering Research and Practice Projects" identified the integration of specialized education and innovation/entrepreneurship in smart manufacturing as a key research direction; the 2021 "14th Five-Year Plan for the Development of Intelligent Manufacturing" explicitly called for improving a multi-tiered talent cultivation system for intelligent manufacturing; and the 2026 "Implementation Opinions on the 'AI + Manufacturing' Special Action," jointly issued by eight government departments, further required universities to deepen the reform of integrating innovation and entrepreneurship with academic disciplines to cultivate interdisciplinary innovative talents suited for the integrated development of AI and manufacturing, thereby forming a full-chain policy support system spanning from top-level design to implementation.

Mainstream Practice Models and Points of Controversy Based on practices at domestic institutions, three mainstream models for integrating innovation and entrepreneurship into smart manufacturing engineering programs have emerged since 2020: The first is the "course-embedded model," which centers on the professional curriculum system and modulates innovation and entrepreneurship education content to be embedded into foundational, core, and practical courses. This model has a low implementation threshold and broad coverage, making it the chosen path for most institutions; however, it is prone to superficial and formalistic integration, making it difficult to achieve deep synergy in competency development. The second is the "project-driven model," which uses innovation and entrepreneurship projects as a vehicle to integrate knowledge from multiple specialized courses. Adopting a "learning by doing" approach, it enables students to simultaneously enhance their core competencies throughout the entire process of project R&D, product design, and commercialization. This model is commonly seen in scenarios such as the "Internet Plus" Innovation and Entrepreneurship Competition and the National Vocational College Skills Competition. While it effectively stimulates students' innovative vitality, it suffers from limited reach and a disconnect from conventional teaching. The third category is the "Industry-Education Collaboration Model," which is based on deep school-enterprise cooperation. It involves joint efforts with industry enterprises to co-develop talent cultivation plans, curriculum systems, practical training bases, and faculty teams, integrating real-world enterprise production projects and technical R&D projects into teaching. This model achieves precise alignment between talent cultivation and industry needs and represents the current mainstream direction for the integration of specialized education and entrepreneurship. However, it places high demands on the robustness of school-enterprise collaboration mechanisms and is prone to issues such as insufficient enterprise participation and the erosion of collaborative mechanisms. Current debates within academic and educational circles primarily focus on three aspects: First, the issue of evaluation criteria for the integration of vocational and entrepreneurial education. Some argue that project implementation rates and entrepreneurial success rates should serve as core indicators, while others contend that the focus should be on enhancing students' innovative thinking and engineering practice capabilities to avoid the utilitarianization of innovation and entrepreneurship education; Second, the issue of differentiated training: whether undergraduate institutions and vocational colleges should establish distinct models for the integration of specialized education and entrepreneurship, and whether vocational colleges should place greater emphasis on technological innovation and workplace-based entrepreneurship rather than traditional commercial entrepreneurship; third, the issue of allocating responsibilities and rights in university-enterprise collaboration: how to balance the talent development objectives of educational institutions with the economic interests of enterprises to establish a long-term, stable collaborative education mechanism.

3. Case Study Analysis of the Smart Manufacturing Program Cluster

This section examines three leading domestic institutions in the development of smart manufacturing program clusters—Wuxi Vocational and Technical College, Shandong Vocational College of Science and Technology, and Shenzhen Pengcheng Technician College—to analyze their practical approaches to integrating specialized education with entrepreneurship and assess the outcomes of these initiatives, thereby distilling replicable and scalable best practices.

(1) Wuxi Vocational and Technical College. A Five-Pronged Integration System of "Job Roles, Courses, Competitions, Certificates, and Innovation/Entrepreneurship" As a Grade A institution under the national "Double High

Plan," Wuxi Vocational and Technical College has designated its smart manufacturing program cluster as a national-level key program cluster. The college has established a five-pronged talent development system for integrating professional education with innovation and entrepreneurship, centered on "job role requirements as the orientation, professional courses as the core, skills competitions as the driving force, vocational certificates as the vehicle, and innovation and entrepreneurship as the goal." In terms of curriculum restructuring, the college has partnered with leading local enterprises such as Wuxi Weifu High-Tech and Bosch Automotive to deconstruct the competency requirements of core smart manufacturing positions. By integrating innovation and entrepreneurship competency indicators into the talent development plan, the college has restructured a four-tier curriculum system comprising "general education courses + professional platform courses + specialized direction courses + integrated innovation and entrepreneurship practice courses." This ensures that 100% of core professional courses incorporate innovation and entrepreneurship elements such as innovative design and technical problem-solving. while also offering dedicated integrated innovation and entrepreneurship courses such as "Smart Manufacturing Innovation and Entrepreneurship Practice." In terms of practical instruction, the institution has partnered with enterprises to establish a Smart Manufacturing Industry College and a national-level industry-education integration practice base, incorporating real-world corporate projects—such as technological upgrades and production line modernization—into the curriculum. In 2025, a faculty-student team from the institution completed four core projects for Wuxi Lihu New Quality Energy-Saving Technology Co., Ltd., including the construction of a smart automated warehouse and the renovation of a three-process-integrated production unit, saving the company over 500,000 yuan annually. Additionally, leveraging innovation and entrepreneurship competitions as a driving force, the college has established a mechanism that "integrates courses with competitions and uses competitions to foster innovation." Over the past five years, students have won more than 30 awards in national innovation and entrepreneurship competitions, with a project implementation rate of 28% and a graduate job-fit rate exceeding 95%. The core advantage of this model lies in its comprehensive coverage of the integration of specialized education and innovation/entrepreneurship across all students and throughout the entire process. Its curriculum restructuring approach is highly replicable and applicable to smart manufacturing-related programs at the vast majority of secondary and higher vocational colleges.

(2) Shandong Vocational College of Science and Technology. A Deeply Collaborative Talent Development Model Through Jointly Established Industry Colleges Shandong Vocational College of Science and Technology focuses on Shandong's manufacturing industry clusters and has jointly established smart manufacturing industry colleges with leading enterprises such as Weichai Power and Goertek, forming a vocational-innovation integration model characterized by "dual-subject entities (school and enterprise) and the integration of industry, academia, research, application, and innovation." The college and enterprises jointly established an Industry College Council, where both parties collaboratively develop talent cultivation plans, build curriculum systems, assemble teaching teams, establish practical training bases, and conduct evaluation and assessment, thereby achieving deep collaboration between the college and enterprises as dual stakeholders. The college and enterprises have jointly developed over 20 specialized and innovation-integrated courses based on real-world industrial scenarios, incorporating corporate technical standards, innovation processes, and project management methodologies into the curriculum. Additionally, 15 senior engineers have been assigned as on-campus corporate mentors to participate in teaching and provide guidance for innovation and entrepreneurship projects throughout the entire process. In terms of innovation and entrepreneurship practice, the Industry College has established a dedicated innovation and entrepreneurship fund and built a smart manufacturing maker space to transform corporate R&D projects into student innovation and entrepreneurship initiatives. Over the past three years, students have participated in more than 80 corporate technological innovation projects and obtained over 60 utility model patents. The university has accumulated 136 invention patents during this period, with technical service revenues reaching 58.6 million yuan and generating an economic benefit of 117 million yuan. The employment rate of graduates at partner enterprises exceeds 60%, and employer satisfaction with graduates' innovation capabilities and job adaptability reaches 98%. The core value of this model lies in resolving the common challenge of "one-sided enthusiasm" in university-industry collaboration. Through the substantive operation of the Industry College, it deeply aligns corporate interests with the institution's talent development objectives. This operational model holds significant potential for replication in regions where leading enterprises are concentrated.

(3) Shenzhen Pengcheng Technician College. A Dual-Track Model Integrating Vocational Education and Entrepreneurship: "Project-Based Learning + Apprenticeship System" Shenzhen Pengcheng Technician College, in response to the demand for high-end smart manufacturing in the Guangdong-Hong Kong-Macao Greater Bay Area, has established a dual-track educational model that integrates vocational education and entrepreneurship through the "new enterprise apprenticeship system" and "project-based learning." This model focuses on cultivating students' technical innovation capabilities and entrepreneurial skills for specific job roles. The college has established deep partnerships with companies such as Huawei and Han's Laser to fully implement the new enterprise apprenticeship system. Upon enrollment, students sign apprenticeship agreements with these companies and participate in a "dual mentor system" involving both the college and the enterprise. Students spend half their time at the college engaged in specialized studies and innovation training, and the other half at the enterprise conducting practical training and developing innovation and entrepreneurship projects, thereby achieving the educational goal of "learning as work, and practical training as entrepreneurship." In terms of instructional implementation, the college has fully adopted project-based teaching, breaking away from the traditional subject-based curriculum system. It has restructured modular teaching content around real-world projects from smart manufacturing enterprises, with each project integrating technical skills training, innovative design, cost accounting, and commercial promotion. The smart manufacturing program cluster has introduced UBTech humanoid robots and Han's Laser

industrial-grade equipment to jointly establish order-based training bases, ensuring a seamless alignment between teaching content and job requirements. Over the past five years, the college's graduate employment rate has consistently remained above 99%, with a self-employment rate of 5%—far exceeding the average for similar institutions. Graduates' average starting salaries are 30% higher than those from traditional training models. The core strength of this model lies in its precise alignment with the talent needs of high-end manufacturing, deeply integrating innovation and entrepreneurship training with apprenticeship-based practical experience. It is particularly suitable for technical colleges and vocational institutions in economically developed regions with high industrial concentration.

4. Aligning Talent Needs with Integrated Education for Specialized and Entrepreneurial Development

With the transformation and upgrading of the smart manufacturing industry, the structure of talent demand has undergone fundamental changes. Based on the *2025 Smart Manufacturing Production Line Talent Competency Research Report* and industry recruitment data, talent demand over the next 3–5 years will exhibit three core trends: First, "competency requirements are shifting from single-skill proficiency to composite, cross-disciplinary capabilities." Smart manufacturing technology involves the integrated application of multiple disciplines, including mechanical engineering, automation, information technology, and artificial intelligence. Enterprises no longer require talent with only single operational skills; instead, they need versatile professionals capable of integrating technologies across fields and solving complex engineering problems. Data indicates that the shortage of skilled personnel in control and execution-related industrial software reaches 69%, with skills in PLC, MES, and industrial robots becoming core recruitment requirements. Second, "innovation capabilities have become a core recruitment metric." More than 85% of smart manufacturing enterprises list technical innovation and problem-solving abilities as core evaluation criteria in their hiring processes, far surpassing the emphasis placed on academic credentials and certifications. Companies not only require graduates to be competent in their current roles but also expect them to drive technological innovation and process optimization to address production pain points, demonstrating the capacity for continuous innovation. Third, "on-the-job entrepreneurial capabilities have become a new direction for talent development." With the rapid growth of specialized, refined, distinctive, and innovative small and medium-sized enterprises, a large number of companies require core backbone talent capable of driving micro-innovation and micro-entrepreneurship from their current positions—that is, "on-the-job entrepreneurs." Graduates are expected to possess cost awareness, project management skills, and market insight, and be able to translate technological innovation into production benefits. This also represents the core direction for integrating specialization and entrepreneurship in smart manufacturing programs at vocational colleges. At the same time, the roles of industry professionals are undergoing a fundamental shift. Repetitive positions such as traditional assembly line operators and quality inspectors are gradually being replaced by AI and robotic arms. Practitioners must transition from "executors" to "human-machine coordinators" and upgrade from "experience-based managers" to "digital and intelligent leaders," with significantly heightened demands for digital skills and AI collaboration capabilities.

Compared to industry talent demands, there are still three key gaps in China's current professional education for intelligent manufacturing engineering: First, "the curriculum is out of step with industrial technological developments." At some institutions, course content remains confined to traditional manufacturing technologies, with insufficient integration of cutting-edge technologies such as the Industrial Internet, digital twins, and artificial intelligence. Course updates lag behind industrial technological advancements, resulting in a significant gap compared to the talent development requirements of the 2026 "AI+Manufacturing" Special Action. Second, "practical instruction is disconnected from real-world industrial scenarios." At most institutions, practical training remains dominated by simulated exercises and verification experiments, lacking support from real-world corporate production projects or technical R&D initiatives. Students struggle to engage with authentic industrial environments, resulting in insufficient engineering practical skills and innovation capabilities; consequently, graduates typically require more than six months to adapt to their roles. Third, "innovation and entrepreneurship education is disconnected from professional education." At some institutions, innovation and entrepreneurship education remains confined to general education courses and entrepreneurship lectures, completely separated from professional education, creating a "two-tiered" phenomenon. Students are unable to integrate innovation and entrepreneurship methodologies with professional technical skills, resulting in innovation and entrepreneurship projects that are detached from industrial realities, difficult to implement, and unable to meet enterprises' demands for innovative talent.

Pathways for Enhancing Talent-Industry Alignment through the Integration of Specialized and Innovation-Entrepreneurship Education The integration of specialized and innovation- entrepreneurship education is the core pathway to bridging the aforementioned gaps and achieving precise alignment between talent development and industry needs. On the one hand, by restructuring the curriculum through this integration—incorporating cutting-edge industry technologies, real-world corporate projects, and innovation-entrepreneurship methodologies into specialized courses—curriculum content can be updated in tandem with industrial technological advancements. This enables students to master the core technologies and innovative methods required by the industry while still in school. On the other hand, by establishing a practice system for the integration of specialization and innovation through industry-education collaboration and university-enterprise cooperation, students can engage in innovation and entrepreneurship practices within real industrial settings. This effectively enhances students' engineering practice capabilities, technological innovation capabilities, and job adaptability, significantly shortening the onboarding period. Furthermore, education integrating specialization and innovation cultivates students' innovative thinking and entrepreneurial awareness, equipping them with the ability to engage in continuous learning and innovation. This enables them to meet the rapidly evolving talent demands of the intelligent manufacturing industry and

achieve long-term alignment between talent development and industry needs.

5. Existing Issues and Optimization Strategies for the Integration of Specialized and Innovative Education

Based on the theoretical research, case analyses, and studies on industry-demand alignment discussed above, the integration of specialized education and innovation/entrepreneurship in the current Intelligent Manufacturing Engineering program still faces four core issues: First, there is a misalignment in conceptual understanding; some institutions still view this integration as a superficial overlay, failing to incorporate innovation and entrepreneurship education throughout the entire talent development process, resulting in a focus on form over substance; Second, the integration of the curriculum system is superficial. In most institutions, the integration of innovation and entrepreneurship remains limited to the fragmented incorporation of a few courses, failing to form a systematic curriculum framework, and the integration remains superficial; Third, the university-enterprise collaboration mechanism is weak. Most university-enterprise partnerships remain at the level of superficial cooperation, such as equipment donations and student internships. Enterprises have not truly participated in the entire talent cultivation process, and the dual-subject education mechanism has not been effectively implemented; Fourth, faculty capabilities are insufficient. Most specialized instructors lack frontline corporate work experience and practical experience in innovation and entrepreneurship, making it difficult to achieve in-depth integration of academic disciplines and entrepreneurship in teaching.

Optimizing Implementation Pathways: In response to the aforementioned issues and drawing on the practical experience of leading institutions in the field, four major optimization pathways are proposed: First, deepen conceptual innovation by establishing an educational philosophy that integrates professional education with innovation and entrepreneurship, grounded in "professional expertise as the foundation, innovation as the core, and entrepreneurship as the extension." This approach integrates innovation and entrepreneurship education throughout the entire talent development process and clarifies differentiated training objectives: undergraduate institutions should focus on cultivating technical R&D and technology transfer capabilities, while vocational colleges should emphasize fostering technical innovation and on-the-job entrepreneurship skills. Second, reconstruct a systematic curriculum framework for the integration of specialized education and innovation and entrepreneurship. Guided by industry-specific competency requirements, design talent development programs using a backward design approach. Integrate innovation and entrepreneurship competency indicators into the teaching objectives, content, and assessment of specialized courses. Establish a three-tiered curriculum framework comprising "general education, specialized education, and practical training" to achieve comprehensive coverage across all courses. Third, we will improve the institutionalized school-enterprise collaborative education mechanism. Using industry-academic colleges as a platform, we will promote in-depth collaboration between schools and enterprises as dual stakeholders, enabling enterprises to participate in every stage of talent cultivation. We will introduce real-world enterprise projects, technical standards, and innovation resources into teaching, and establish a long-term cooperative mechanism where schools and enterprises share benefits and risks. Fourth, we will build a "dual-qualified, dual-competent" faculty team for the integration of specialization and innovation. We will encourage professional faculty to undertake on-the-job training at the front lines of enterprises to enhance their practical, innovation, and entrepreneurship capabilities; recruit senior corporate engineers and leading innovation and entrepreneurship talents as part-time instructors, and establish a two-way faculty exchange mechanism between schools and enterprises to comprehensively enhance the teaching faculty's ability to integrate professional education with innovation and entrepreneurship.

6. Conclusion

The deep integration of innovation and entrepreneurship with professional education in the Smart Manufacturing Engineering program is an inevitable requirement for adapting to the transformation and upgrading of China's manufacturing sector and building a manufacturing powerhouse, as well as a core reform direction for the development of new engineering disciplines and the enhancement of vocational education quality. This study finds that the integration of innovation, entrepreneurship, and professional education in China's smart manufacturing sector has currently formed three mainstream practice models: curriculum-embedded, project-driven, and industry-education collaboration. Leading domestic institutions have achieved significant educational outcomes through practices such as the integration of "job positions, courses, competitions, certifications, and innovation," the joint establishment of industry colleges, and dual-track apprenticeship systems. However, overall, the integration of specialization and innovation still faces challenges such as conceptual misunderstandings, superficial curriculum integration, superficial industry-academia collaboration, and insufficient faculty capabilities, failing to fully meet the smart manufacturing industry's demand for interdisciplinary innovative talent. Moving forward, the reform of integrating innovation and entrepreneurship into smart manufacturing engineering programs must be guided by industry talent needs and centered on industry-education integration and school-enterprise collaboration. It should be systematically advanced across four dimensions—conceptual innovation, curriculum restructuring, mechanism refinement, and faculty development—to truly achieve a comprehensive and in-depth integration of innovation and entrepreneurship education with professional education throughout the entire educational process. This will ensure the cultivation of more high-quality, multidisciplinary talents who possess professional competence, an innovative spirit, and entrepreneurial capabilities, thereby supporting the high-quality development of China's smart manufacturing industry.

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