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RESEARCH ARTICLE

An Innovation Talent Cultivation Mechanism for Robotics in the Digital-Intelligent Era: Exploration and Practice at Wuhan University

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Abstract Cultivating talents in robotics requires the integration of multiple disciplines, including mechanical engineering, electronics, computer science, and control engineering. The rapid expansion of the robotics industry in recent years has highlighted a significant talent gap and compelled universities to raise the standards of talent development in this field. This research examines the distinctive features of talent cultivation in robotics, draws on the practices of Wuhan University's intelligent robotics program, and incorporates the concept of digital-intelligent education to propose an innovative talent cultivation framework termed system reconstruction and a fourfold integration education. This research emphasizes the importance of digital-intelligent interdisciplinarity and reports on the establishment of a progressive and comprehensive professional curriculum system. It also presents a supporting model that includes research-activated education, industry-driven education, competition-enhanced education, and interdisciplinary education, thereby creating a project-driven innovation practice platform and talent cultivation mechanism. Guided by systematic reconstruction and fourfold integration education mechanism, the digital-intelligent interdisciplinary curriculum and project-driven practice platform have significantly improved students' professional knowledge, innovative ability, and sense of social responsibility. This mechanism has not only improved the quality of talent cultivation in intelligent robotics but has also increased the impact of academic competitions and garnered widespread acclaim from peers.

Keywords robotics talent cultivation mechanism, digital-intelligent education, interdisciplinary integration, project-driven platform, industry–academia collaboration

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1 Introduction

With the rapid development of China's economy and society, robotics has emerged as one of the country's strategic industries. It plays a vital role in transforming and upgrading the manufacturing sector and improving social efficiency and citizens' quality of life (Feng et al., 2020; Zhang et al., 2017). The 14th Five-Year Plan for National Economics and Social Development of the People's Republic of China for the robotics industry development states that by 2025, China will become a global hub for robotics technology innovation, a center for high-end manufacturing, and a new leader in integrated applications. The plan seeks to establish leading internationally competitive companies and industrial clusters, which doubles the density of robots in the manufacturing sector. This plan provides a clear direction for the development of the robotics industry in China. The growth of the robotics sector relies heavily on a substantial number of professionals with specialized knowledge and innovative capabilities. Therefore, high-quality talent cultivation in robotics has become a challenge for higher education institutions (Zhang & Xu, 2019). As early as 2016, the Ministry of Education (MOE) of the People's Republic of China had already introduced an undergraduate program in robotics engineering. Given the close integration of industry and education within the context of emerging engineering disciplines, domestic institutions had explored extensively talent cultivation in this field (Wang et al., 2024a). However, a mature talent cultivation mechanism for intelligent robotics had yet to be established (Wang et al., 2025; Zhang et al., 2022).

Robotics is an interdisciplinary field incorporating technologies from mechanical engineering, electronics, computer science, and control engineering (Cai, 2015; Liu et al., 2022). It emphasizes the integration of theory and practice and necessitates a curriculum that not only draws from mechanical engineering, control engineering, and software engineering but also highlights the unique features and innovations of robotics systems. Moreover, demands in the robotics industry and the evolving landscape have intensified in recent years. With the rise of AI, new robotics technologies and business models are emerging constantly and robotics technology is evolving rapidly (Li, 2023). As a result, robotics knowledge system has clear characteristics of seamless integration, frontier development, and groundbreaking innovation.

At the same time, robotics engineering education requires a strong connection between theory and practice. However, traditional practical teaching has focused on cognitive internships and course designs, consisting of mere observation and formulaic design. Students in traditional instruction contexts acquire knowledge passively. The practical content is not aligned closely with new robotics technologies and AI algorithms. The disparity results in a lack of immersion and innovative practical contexts (Hua, 2024; Ye et al., 2024). Therefore, cultivating innovative robotics talents requires the design of multi-level practical instruction. In addition to traditional basic engineering experiments, comprehensive experimental instruction, and active participation in academic competitions, the robotics talent cultivation mechanism should also incorporate cutting-edge AI technologies and address the real needs of the industry.

As mentioned above, the challenges in cultivating innovative talent in robotics stem from two main approaches: First, the curriculum system should integrate multidisciplinary content, including mechanical engineering, electronics, computer science, and control engineering, while also incorporating essential knowledge in AI and machine learning. Second, the practical instruction requirements should address needs across various levels, including academic disciplines, competitions, industry, and research, and balance their relationships and coordination. This requires a clear focus on practical instruction, a progressive approach, and comprehensive coverage. These challenges demand higher standards for robotics curriculum systems and practical instructions, as traditional talent cultivation mechanisms can no longer meet the demands of industrial development.

Since 2018, the School of Power and Mechanical Engineering at Wuhan University has integrated a robotics curriculum into its mechanical engineering program. Leveraging the school's strong research foundation in robotic design, modelling, planning, and controlling, the department offers courses such as robotics, robotics sensing, vision and control, and robotics design. Moreover, participation in the robotics competitions across the campus has been incorporated into the innovation credit score system. In 2022, the university launched an intelligent robotics experimental course and introduced a comprehensive 165-credit program. During these teaching practices, challenges have arisen, such as difficulties in understanding the professional scope, a lack of a holistic knowledge structure, and a gap between practical skills and the rapidly evolving societal demands in robotics.

Many universities in China are actively exploring and developing curriculum systems for robotics engineering programs, but a unified system and standard have yet to be established. Each university adapts and optimizes its curriculum based on its academic strengths and characteristics (Wang et al., 2024b). A key challenge is to refine the interdisciplinary foundation courses at the undergraduate level and integrate them with the university's academic strengths and resources to build a new curriculum that meets the needs of undergraduate education. This system should lay a solid foundation of theoretical knowledge in robotics and better prepare students for future research and development in cutting-edge fields, such as autonomous vehicle technology, robotic surgery, and industrial automation.

To align with the development trends of robotics technology and cultivate high-quality talent in intelligent robotics, Wuhan University has positioned the School of Power and Mechanical Engineering as a demonstration zone for talent cultivation in robotics. By optimizing educational methods and educational concepts through the implementation of intelligent robotics courses and intelligent robotics experimental courses, the university is aiming to train talents with innovative abilities to solve robotics technology problems and promote technology integration and application, thereby contributing to the high-level development of China's robotics industry. Guided by its digital-intelligent talent cultivation philosophy and taking advantage of interdisciplinary integration, the Wuhan University has proposed a systematic reconstruction and fourfold integration education mechanism for innovative talent cultivation in robotics. The main idea is to emphasize the intersection of digital intelligence, construct a progressive and comprehensive professional curriculum system, and establish a supporting model that integrates science and education, industry and education, competitions and education, and interdisciplinary cooperation. This supporting model forms an innovation-driven talent cultivation mechanism.

2 Talent Cultivation Mechanism for the Robotics Program

2.1 | Constructing a Three-Stage Progressive Practical Curriculum System with Integration of Interdisciplinary Strengths

As an interdisciplinary frontier field, robotics engineering requires the integration of knowledge from mathematics, physics, mechanical engineering, industrial design, electronic engineering, automation technology, and AI. To accommodate this innovative integration, this research developed an optimized curriculum system, especially by strengthening the mathematical foundation and integrating digital-intelligent courses. The research restructured both basic and specialized courses to form an intelligent robotics curriculum system that incorporated multidisciplinary knowledge. Moreover, in this research, teaching has been improved to shift from a knowledge-based instructional paradigm to an engineering practice-based approach. In this system, the cultivation of innovative thinking, training in innovation capability, and practice in the innovation process are integrated into the entire professional development process. This system enables students to apply specialized knowledge in practice and improve their innovative literacy as well as engineering skills, ultimately leading to the construction of a three-stage curriculum system, as shown in Figure 1.

In the foundation course stage, to closely relate to the core theoretical courses in robotics and meet the trend of intelligent robotics technology, the foundational curriculum has been enriched with the digital-intelligent course system, in addition to traditional platform courses, such as mathematics, physics, and electronics. Specifically, courses such as data structures, program design, probability theory, and mathematical statistics have been introduced to ensure that the foundational curriculum covers the digital-intelligent, physical, and engineering fundamentals required for advanced robotics. These courses provide students with a solid theoretical foundation to master robotics design optimization, robotics manufacturing, and intelligent control.

In the major course stage, courses such as mechanical principles, mechanical design, robotics, drive and control for robots, sensing and vision for robots, and robot operating systems are central to the curriculum. These courses cover topics, such as robot structural design, low-level control, and motion planning, while also deeply integrating AI technologies. Emphasis is placed on the intelligent, collaborative, flexible, and systematic nature of robotics. During theoretical instruction, special attention is given to practical applications through simulations and hands-on exercises, focusing on fundamental practices in robot configuration, control, sensing, and planning to facilitate both the mastery and flexible application of core knowledge. This stage also integrates the characteristics and strengths of the discipline's evolution and uses digital-intelligent courses to refine

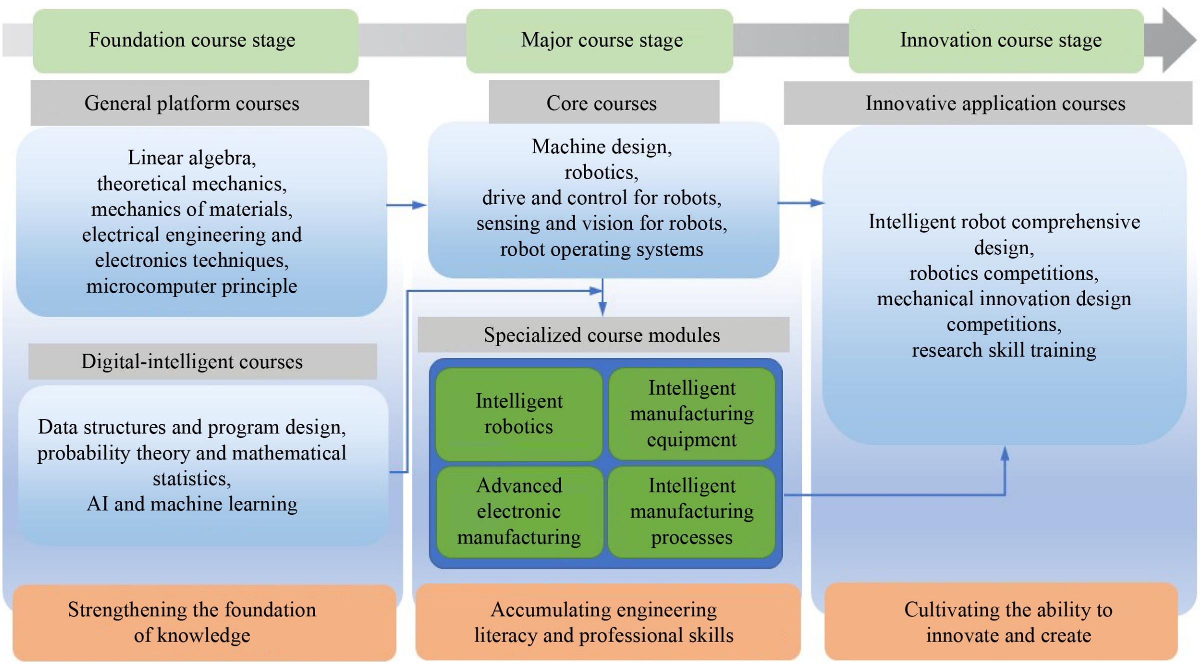

Figure 1 Three-stage progressive practical curriculum system.

and enhance specialized courses. Four specialized course modules, namely, intelligent robotics, intelligent manufacturing equipment, advanced electronic manufacturing, and intelligent manufacturing processes, have been established to provide students with practical applications for learning professional robotics knowledge.

In the innovation course stage, several comprehensive practice and research training courses, such as intelligent robot comprehensive design, robotics competitions, mechanical innovation design competitions, and research skills training, have been introduced. Innovative application topics are mainly derived from major national projects, national-level academic competitions, and industry application projects, focusing on multidisciplinary knowledge and practical innovation. The courses adopt a project-based teaching approach, with students working in groups under the guidance of mentors on comprehensive projects and experiencing the entire process from research to solution implementation. Moreover, this innovative application stage relies on robotics competitions, such as China University Robot Competition and National Undergraduate Mechanical Innovation Design Competition, encouraging students to innovate and create while encouraging their pioneering spirit, pursuit of excellence, innovation ability, and teamwork skills. These practical courses provide students with a solid innovation practice that addresses the challenge of applying knowledge to real-world scenarios and offers opportunities to explore cutting-edge robotics technologies, develop practical abilities, enhance participation and real-time engagement, and stimulate critical thinking and agile decision-making skills, ultimately contributing to the development of innovative talents.

2.2 | Building a Project-Driven Innovation Practice Platform and Cultivation Mechanism to Integrate Research, Industry, Competition, and Interdisciplinary Strengths

Talent cultivation in robotics requires the integration of theoretical learning with practical research and development, as well as the incorporation of the latest advances in robotics planning and control strategies, AI and machine learning algorithms, operating systems, and industrial software into the curriculum. To achieve this, the research created the collaborative talent cultivation mechanism based on the fourfold integration education, as shown in Figure 2. This mechanism seamlessly combines theoretical teaching, research training, internships, practical training, and academic competitions. In this research, a multilevel and project-driven innovation practice platform and cultivation mechanism has been established to incorporate research-activated education, industry-driven education, competition-enhanced education, and interdisciplinary education. Innovation outcomes are recognized for academic credit, and research activities and academic competitions are integrated into the curriculum. These elements are also linked to faculty recognition, awards, scholarships, and postgraduate recommendations. These motivate students and ensure that innovation practice activities are covered for all undergraduates comprehensively. In this mechanism, due to limited class time, students are encouraged to engage in

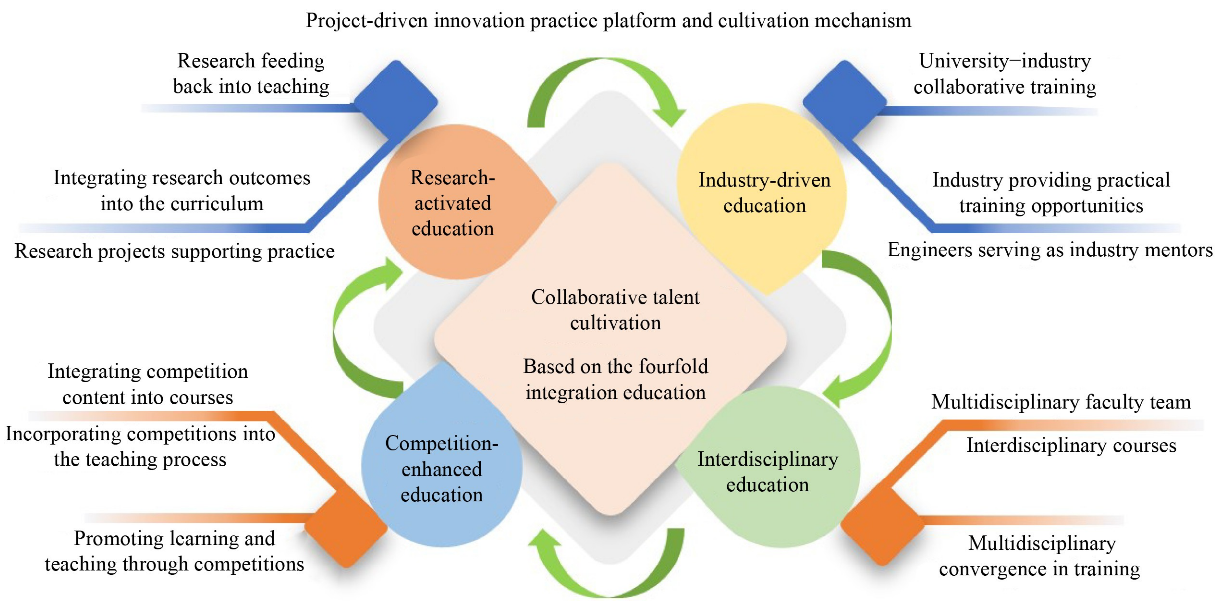

Figure 2 Collaborative talent cultivation platform based on fourfold integration education.

exploratory activities outside of class, thereby cultivating digital expertise and intelligence-driven skills.

In research-activated education, Wuhan University promotes the integration of research project outcomes into course content and incorporates research findings from robotics research and development, manufacturing, AI, and industrial software into both the curriculum and practical teaching. This approach provides academic lectures for undergraduates to encourage their participation in research activities and guide them to engage in real-world projects, such as humanoid robots, precision instruments, and patrol robots.

In industry-driven education, guided by the needs of the robotics industry, leading companies, such as Goneo Group Co., Ltd. and Guangxi Liugong Machinery Co., Ltd., and innovation talent training institutions, such as Shenzhen Innox Academy, are invited to collaborate with Wuhan University. This cooperation bridges the gap between industry and academia, guides students to understand industry requirements, enhances their sense of achievement in learning, and engages in the development of cutting-edge robotics products.

In competition-enhanced education, Wuhan University has incorporated academic competitions, such as China University Robot Competition and National Undergraduate Mechanical Innovation Design Competition, into the curriculum. By integrating theoretical education with practical competition experience, Wuhan University provides students with opportunities to enhance their knowledge, skills, and values through active participation in these events.

In interdisciplinary education, following the curriculum system, Wuhan University has formed an interdisciplinary university–industry collaborative teaching team which consists of faculty from the School of Power and Mechanical Engineering, School of Computer Science, School of Geodesy and Geomatics, and Global Navigation Satellite System Research Center, as well as mentors from Shenzhen Innox Academy. This collaborative teaching team reviews the content and logical structure of each course and reduces the boundaries between disciplines. The curriculum considers the characteristics of robotics, introducing innovative teaching methods such as project-driven learning and flipped classrooms to guide students in applying multidisciplinary knowledge to solve real-world engineering problems.

3 Talent Cultivation Practices and Outcomes

Under the proposed innovative talent cultivation mechanism, the talent cultivation practice in robotics-related fields is closely aligned with the concept of cultivating digital-intelligent talents through continuous iteration and optimization. Since 2022, the intelligent robotics course trained approximately 60 undergraduates per cohort. All students participated in various academic competitions and research activities, with an average of over 89 innovation credits recognized annually over the past three years, ranking at the top of Wuhan University in terms of per-capita innovation credits. Of the student innovation and entrepreneurship projects approved by the School of Power and Mechanical Engineering, 62% are related to robotics. Students contributed to more than 30 valid patents and published more than 50 papers, which demonstrated a steady improvement in their innovative practice abilities. By integrating digital-intelligent educational concepts, the curriculum system incorporates AI technologies and data analysis tools and enables students to build a solid theoretical foundation while developing outstanding innovation skills and practical abilities. The overall quality of talent cultivation has significantly improved, with the postgraduate enrollment rate increasing from 40% to 60%. Graduates have been admitted to prestigious institutions, including Tsinghua University, Huazhong University of Science and Technology, Shanghai Jiao Tong University, Zhejiang University, the Hong Kong University of Science and Technology, Carnegie Mellon University, École Polytechnique Fédérale de Lausanne, and the National University of Singapore. Furthermore, graduates are highly sought after by leading high-tech manufacturing enterprises, such as Huawei Technologies Co., Ltd., Commercial Aircraft Cooperation of China Shanghai Aviation Industrial (Group) Co., Ltd., China General Nuclear Power Corporation, Yangtze Memory Technology Co., Ltd., and China Railway Rolling Stock Co., Ltd. The outstanding quality of talent cultivation has been widely recognized by both academia and industry.

Under the guidance of the progressive and comprehensive practical curriculum system, students in this program have achieved continuous breakthroughs in robotics-related academic competitions and secured over 50 national-level awards. Notably, the university's robotics team won the national first prize in the China University Robot Competition for six consecutive years and won the Southern Regional Championship for two consecutive years. The team placed third in the country in 2019, advanced to second place in 2020, and won the national championship in 2021. In 2022, the team represented China in the Asia–Pacific Broadcasting Union (ABU) Robot Contest (ROBOCON), competing against 21 teams from 11 countries and regions, and won the prestigious ABU ROBOCON award, the highest honor of the event. In 2023, the team achieved remarkable results again, secured the third place in the "Casting Flowers over Angkor Wat", and won two first prizes in the Robotic Equestrian competition. In 2024, the team won the first prize in the Operations Challenge competitions. The team's outstanding performance in these events received widespread media coverage from outlets such as China Media Group, Japan's Nippon Hoso Kyokai, and Shandong TV, and attracted the attention of the international academic peers, including the University of Tokyo. As the only university in China invited to participate in the 8th China International Robot Show, the team received high praise from industry professionals and entrepreneurs. These accomplishments have greatly strengthened Wuhan University's influence in cultivating talent in the field of intelligent robotics and set a benchmark for innovative and internationally oriented education.

The innovative talent cultivation mechanism for the intelligent robotics program proposed in this research has attracted widespread attention from our academic peers. More than 10 universities, including the University of Science and Technology Beijing, the University of Electronic Science and Technology of China, Northeastern University, and Xiamen University, have visited Wuhan University to exchange and observe the practical training mechanisms. Moreover, over 20 robotics competition training sessions have been conducted and promote continuous iterations and advances in competition robotics technologies. Faculty members have been invited by more than 10 universities, including Changsha University of Science and Technology, Hunan University of Science and Technology, as well as Guangxi University, to share their experiences in professional curriculum development. They have also delivered keynote presentations on professional development at prominent conferences, including the annual meeting of the Teaching Steering Committee for Mechanical Engineering Programs of the MOE, the Joint Conference of Deans of the National College of Mechanical Engineering, the Central China Industry–University–Research–Training Cooperation Summit for Mechanical and Electrical Engineering, and the annual meeting of the Hubei Institute of Mechanical and Electrical Engineering. These contributions have received significant recognition and appreciation from academic and industrial peers.

4 Conclusions

Based on the principles of strengthening foundations, encouraging innovation, broadening perspectives, and promoting interdisciplinarity, the School of Power and Mechanical Engineering at Wuhan University has drawn on its years of experience in cultivating robotics talent to develop an innovative approach to talent cultivation for the Intelligent Robotics program. This mechanism, characterized by system reconstruction and fourfold integration education framework, represents a forward-looking approach to talent cultivation in emerging engineering disciplines.

As for system reconstruction, building on the disciplinary strengths of Wuhan University in the humanities, sciences, medicine, and engineering, the reforming curriculum promotes innovative education and innovative learning through incentive mechanisms. It encourages academic leaders, nationally-recognized experts, frontline researchers, and industry professionals to integrate their involvement in major national and industrial projects into the talent cultivation process. By designing interdisciplinary curriculum restructuring, incorporating digital-intelligent courses, and introducing innovative courses that focus on experimental innovation, research training, and academic competitions, a three-stage practical curriculum system has been restructured.

As for fourfold integration education, a project-driven practical mechanism that is underpinned by four dimensions of integration has been established. These dimensions are synergy of science and education, collaboration between industry and education, alignment of competitions and teaching, and interdisciplinary convergence. This mechanism encourages students to actively engage in real-world scientific research, enterprise research and development, technology transfer, and interdisciplinary innovation projects. By applying their professional knowledge and skills, students analyze problems, develop strategies, formulate solutions, and validate these solutions through practical implementation. This approach develops students' practical abilities and promotes diverse and differentiated talent cultivation methods.

The innovative talent cultivation mechanism for intelligent robotics programs has demonstrated effective results through practical validation. The proposed system reconstruction and fourfold integration education framework successfully integrate the principles of digital-intelligent education and stimulate students' learning potential. It is a practical and effective approach to cultivating innovative talent in the field of robotics engineering.

Conflict of Interest The authors declare that they have no conflicts of interest.

Data Availability Statements The authors confirm that all data generated or analyzed during this study are included in this published article.

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