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Original Paper

Research on the Development and Implementation of Robotics Courses in Higher Vocational Colleges under the Context of Industry Academy Construction

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Abstract

With the rapid advancement of intelligent manufacturing and robotics industries in China, the demand for skilled professionals such as robotics application engineers has grown significantly. Higher vocational colleges, as key institutions for cultivating technical talents, urgently need to explore course development and implementation pathways that align with industry competency requirements, particularly in the context of industry academy construction. Based on the robotics industry academy jointly established by Sichuan Yangtze Vocational College and Zhejiang Haidu Intelligent Equipment Co., Ltd., this study adopts a mixed approach of literature review, enterprise research, curriculum design, and practice-based validation. It systematically analyzes the existing challenges in robotics course development and implementation, including goal deviation, insufficient resource integration, lagging smart curriculum construction, weak school-enterprise collaboration, and one-dimensional evaluation systems. On this basis, a competency-oriented modular curriculum system was constructed, smart course resources integrating artificial intelligence and virtual simulation were developed, a dual-mentor collaborative teaching mechanism between schools and enterprises was formed, and a diversified evaluation system was established. The findings indicate that this model significantly enhances students' practical abilities and professional literacy, while achieving precise alignment between curriculum content and industrial needs. The research provides replicable and transferable experience for robotics program construction and the development of industry academies in higher vocational education.

Keywords

Industry Academy, Robotics Course, Modular Teaching, School-Enterprise Collaboration, Smart Curriculum

1. Introduction

1.1 Research Background: Intelligent Manufacturing and Robotics Industry Demand

The rapid development of intelligent manufacturing has placed robotics at the core of industrial transformation and upgrading. Over the past decade, robotics technology has expanded from traditional industrial automation into service, logistics, healthcare, and emerging fields such as new energy and smart construction. According to recent reports from the International Federation of Robotics, global installations of industrial robots have grown at an annual rate of more than 15%, with China accounting for nearly half of the new installations worldwide. This industrial momentum has generated a strong demand for technical talents with specialized competencies in robotics programming, debugging, integration, and system maintenance.

In particular, enterprises in the Yangtze River Basin and the Chengdu–Chongqing economic zone have accelerated their adoption of intelligent equipment, which highlights a shortage of robotics application engineers and related skilled professionals. Higher vocational colleges, as frontline providers of practice-oriented education, must therefore respond to industry demand by developing systematic curricula that cultivate both foundational knowledge and practical skills. Without such targeted efforts, the gap between workforce supply and industrial demand will continue to widen, constraining regional economic growth and technological competitiveness.

1.2 Policy Context: "Robot+ Action Plan" and "Modern Industry Academy Guidelines"

National and regional policy initiatives have provided strong guidance for vocational institutions to prioritize robotics education. The "Robot+ Action Plan" (2023) issued by the Ministry of Industry and Information Technology explicitly positions robotics as a strategic driver of China's manufacturing transformation, calling for cross-industry applications and large-scale workforce development. Similarly, the "14th Five-Year Plan for the Development of the Robotics Industry" emphasizes the cultivation of compound talents through collaboration between schools, enterprises, and research institutions.

Complementing these industrial policies, the Ministry of Education and the Ministry of Industry and Information Technology jointly issued the "Guidelines for the Construction of Modern Industry Academies (Trial)" in 2020. The guidelines encourage universities and vocational colleges to establish industry academies, integrating the "education chain, talent chain, and innovation chain" with the "industrial chain." This policy framework urges institutions to adopt competency-based, modular course systems that are co-developed with enterprises, thereby ensuring that teaching content, practice platforms, and evaluation standards remain aligned with industry needs. Together, these policies create a favorable institutional environment for higher vocational colleges to design and implement robotics courses that not only enhance student employability but also serve regional industrial upgrading strategies.

1.3 Research Objectives and Scope of the Study

In response to the dual pressures of industrial demand and policy reform, this study aims to explore a systematic approach to robotics curriculum development and implementation within the context of industry academy construction. The objectives of this research are threefold:

(1) To construct a competency-oriented modular robotics curriculum system that aligns closely with the core tasks and skills required of robotics application engineers.

(2) To design and develop smart curriculum resources, including digital learning materials, virtual simulation platforms, and AI-enhanced teaching tools, that can enrich teaching and learning experiences.

(3) To establish an implementation and evaluation mechanism that leverages school–enterprise collaboration, particularly the dual-mentor model, and incorporates multi-dimensional feedback from teachers, enterprises, and students.

The scope of this study focuses on the case of Sichuan Yangtze Vocational College in partnership with Zhejiang Haidu Intelligent Equipment Co., Ltd. Within this setting, the research investigates curriculum design, resource development, teaching implementation, and evaluation practices as a holistic system. Although the study emphasizes robotics education in the Chinese higher vocational context, its findings hold broader relevance for vocational institutions worldwide seeking to integrate industrial demand with education reform.

2. Literature Review

2.1 Development of Industry Academies in Vocational Education

The concept of the industry academy has emerged as a central strategy for aligning vocational education with the rapid evolution of industrial needs. In China, the Ministry of Education formally introduced the Modern Industry Academy model in 2020, emphasizing integration of the “education chain, talent chain, and innovation chain” with the “industrial chain.” This approach encourages universities and vocational colleges to work closely with enterprises to co-develop curricula, share resources, and build joint training platforms. Studies have shown that such models enhance employability by embedding real-world projects, industrial standards, and enterprise mentorship into classroom teaching.

Internationally, similar models can be observed in Germany’s dual system, which integrates classroom instruction with enterprise-based apprenticeships, and in the U.S. community college–industry partnership programs, which are oriented toward regional workforce development. These examples indicate that industry–education integration is a common trend in the development of global vocational education.

2.2 Robotics Curriculum Models in Domestic and International Contexts

Robotics curricula have been widely studied as a key driver of technical skill cultivation. In domestic vocational institutions, robotics courses often focus on industrial robot operations, programming, and maintenance, with growing emphasis on advanced applications such as vision-based sorting and collaborative robotics. Research by Chinese scholars suggests that curricula should be task-oriented and competency-based, combining theoretical foundations with practical problem-solving. Project-based learning and virtual simulation have been introduced to address the limitations of expensive hardware and high maintenance costs.

Internationally, robotics curricula in vocational and technical education often emphasize STEM integration and interdisciplinary learning. For example, European initiatives incorporate robotics into mechatronics programs, highlighting hands-on training with advanced automation systems. In the U.S., robotics is frequently embedded into engineering technology and applied science degrees, where curricula stress critical thinking, innovation, and adaptability. Although these models demonstrate strong relevance to industry, they also vary in terms of resource intensity, teaching philosophy, and scalability. A comparative analysis suggests that while international programs focus on innovation and interdisciplinarity, domestic programs are still more application-driven and hardware-centered, creating an opportunity for hybrid models that blend both perspectives.

2.3 Gaps in School–Enterprise Collaboration and Competency-Based Curriculum

Despite significant progress, several gaps remain in the development and implementation of robotics curricula. First, school–enterprise collaboration is often limited to short-term cooperation or superficial project partnerships, lacking deep integration in curriculum co-design, resource sharing, and long-term talent cultivation. In practice, enterprises may provide internship opportunities but seldom engage systematically in teaching design or assessment. This weakens the intended benefits of the dual-mentor model and reduces the authenticity of learning experiences.

Second, competency-based education (CBE), though widely advocated, is not yet fully realized in many vocational colleges. Traditional curricula remain heavily knowledge-centered, with insufficient translation of occupational standards into learning modules and performance indicators. Furthermore, the absence of dynamic adjustment mechanisms means curricula are slow to integrate emerging technologies such as artificial intelligence, digital twin, and industrial internet applications. This misalignment between learning outcomes and industrial requirements perpetuates the talent–skill gap. Addressing these challenges requires systematic frameworks that institutionalize collaboration, embed competency standards into course design, and ensure continuous updating of content.

2.4 Theoretical Basis for Modular Robotics Course Design

The development of modular robotics curricula draws upon several well-established educational theories. Competency-based education (CBE) provides the foundation by positioning occupational competencies as the core outcomes of learning. Under this framework, courses are organized into modules that correspond to discrete tasks and skills required in industry. Each module represents a self-contained learning unit with clear objectives, resources, and assessment criteria, allowing flexibility and adaptability in teaching.

Constructivist learning theory further supports this design by emphasizing active, experiential learning. In robotics education, constructivism is reflected in project-based and problem-based learning activities, where students acquire knowledge through solving real-world engineering challenges. Work-process-oriented curriculum theory, widely applied in German vocational education, also influences modular design by aligning learning tasks directly with industrial workflows. Finally, systems theory underpins the continuous feedback mechanism, in which course evaluation and industrial feedback inform the dynamic refinement of teaching modules. Together, these theoretical foundations justify the shift toward modular, practice-oriented, and industry-aligned robotics curricula in higher vocational education.

3. Research Methodology

3.1 Research Design

This study adopts a mixed-methods research design that integrates both qualitative and quantitative approaches in order to provide a comprehensive understanding of robotics curriculum development and implementation. The qualitative component centers on semi-structured interviews with enterprise engineers, faculty members, and curriculum developers to capture in-depth insights into industry needs, teaching challenges, and practical considerations. The quantitative component involves surveys of students and employers to measure perceptions of learning outcomes, curriculum relevance, and employability improvement.

To validate the proposed curriculum model, a pilot teaching intervention was conducted in two robotics courses (Robotics Programming and Debugging and Robotics Vision Sorting). These pilot courses served as testbeds for evaluating the feasibility of modular design, the integration of digital resources, and the dual-mentor teaching mechanism. Through triangulation of data sources—surveys, interviews, and pilot course results—the study ensures both breadth and depth of analysis, enhancing reliability and validity.

3.2 Data Collection Sources

The study relies on multiple data sources to ensure that findings are representative and grounded in practice.

(1) Enterprises: Data were collected from five partner companies in the robotics and intelligent equipment sector, focusing on required competencies, recruitment patterns, and performance expectations. Enterprise engineers also participated as co-mentors in pilot courses, providing valuable first-hand feedback.

(2) Faculty: Ten instructors from Sichuan Yangtze Vocational College's robotics and automation department contributed perspectives on teaching content, instructional challenges, and their experiences with integrating enterprise resources into coursework.

(3) Students: Surveys and focus groups were conducted with 120 students enrolled in robotics-related programs. Students provided feedback on curriculum content, teaching methods, and perceived skill development.

(4) Industry Reports: Secondary data were drawn from national policy documents (e.g., Robot+ Action Plan), industry associations, and global robotics reports. These sources offered benchmarks for situating the study within broader industrial and educational trends.

Table 3.1 Overview of Data Sources and Respondents

Data Source	Participants / Documents	Method of Collection	Purpose of Data Use
Enterprises	5 partner companies, 12 engineers	Interviews, curriculum workshops	Identify core competencies, validate curriculum content
Faculty	10 instructors	Focus groups, surveys	Evaluate teaching challenges, resource needs
Students	120 students	Surveys, focus groups	Assess learning outcomes, feedback on pilot courses
Industry Reports	8 national & international reports	Document analysis	Provide policy and industry context

3.3 Analysis Framework and Evaluation Indicators

The analysis is guided by a three-dimensional evaluation framework:

(1) Curriculum Development Dimension—Examines whether the curriculum structure and modular design reflect occupational standards and enterprise requirements. Indicators include alignment with competency frameworks, integration of emerging technologies, and quality of digital resources.

(2) Implementation Dimension—Focuses on the effectiveness of the dual-mentor model, authenticity of teaching scenarios, and student engagement. Indicators include teaching process quality, enterprise mentor involvement, and application of “Four Real” scenarios.

(3) Outcome Dimension—Assesses the actual impact of the curriculum on student performance and employability. Indicators include theoretical knowledge mastery, practical skill proficiency, problem-solving ability, and enterprise satisfaction.

Table 3.2 Evaluation Framework and Indicators

Dimension	Indicators (Sample)	Data Source
Curriculum Development	Alignment with industry standards; use of AI/simulation; availability of modular resources	Faculty feedback, document analysis
Implementation	Dual-mentor participation; student engagement in	Observation, interviews

	projects; authenticity of scenarios	
Outcomes	Knowledge mastery; practical skills; problem-solving; enterprise satisfaction	Student surveys, employer feedback

This framework ensures that both processes (curriculum design and teaching) and outcomes (student performance and industry recognition) are systematically evaluated. By combining qualitative and quantitative evidence, the study produces a holistic assessment of robotics curriculum innovation in the context of industry academy construction.

4. Development of Modular Robotics Curriculum

The design of a robotics curriculum for higher vocational education must begin with a clear understanding of industry-required competencies. Based on enterprise research, job task analyses, and feedback from both employers and instructors, this study outlines a competency-driven approach to curriculum design. The process involves four steps: competency analysis, modular framework construction, integration of digital technologies, and validation through a pilot course example.

4.1 Competency Analysis of Robotics Application Engineer Positions

Robotics application engineers are central to intelligent manufacturing, responsible for tasks ranging from system debugging and integration to vision-based automation. Competency analysis was conducted to identify the specific knowledge domains, core skills, and performance expectations associated with key roles in robotics-related occupations. The analysis covered positions such as debugging engineers, integration engineers, welding engineers, vision engineers, PLC developers, and maintenance engineers.

Table 4.1 Competency Mapping for Robotics Application Engineers

Position Type	Core Competency	Knowledge Domain	Skill Level (1–5)
Robotics Debugging Engineer	Electrical and software debugging	Circuit design, PLC programming, sensor calibration	4
Robotics Integration Engineer	System integration and deployment	Automation systems, communication protocols, robotics middleware	5
Robotics Welding Engineer	Process control and precision operation	Welding technology, mechanical design, safety standards	3
Robotics Vision Engineer	Machine vision application	Image processing, computer vision, AI algorithms	4
PLC Development	Programming and	Embedded systems, ladder logic, HMI	4

Engineer	control logic	interface design	
Robotics Maintenance Engineer	Equipment operation and troubleshooting	Preventive maintenance, diagnostics, fault analysis	3
Robotics Application Engineer	Project-oriented implementation	Cross-disciplinary integration, teamwork, problem-solving	5

The results of this competency mapping highlight three important insights:

① Diversity of Skill Domains—Competencies span across electrical, mechanical, and software engineering, requiring modular learning units.

② Different Depth Requirements—Some positions demand advanced expertise (e.g., integration engineers), while others focus on applied operational proficiency (e.g., maintenance engineers).

③ Foundation for Modular Design—The mapping provides the basis for developing seven interrelated learning modules, each linked to a specific job function, thus ensuring that curriculum content mirrors industrial practice.

The competency mapping highlights that robotics-related roles are interdisciplinary, demanding expertise across mechanical, electrical, and software domains. More importantly, skill levels vary by position: while integration engineers and application engineers require advanced capabilities in system deployment and project management, maintenance engineers and welding engineers emphasize applied operational skills. This analysis provides the foundation for translating occupational requirements into structured course modules.

4.2 Construction of Modular Course Framework

Based on the competency mapping, a modular course framework was designed to ensure that learning outcomes align with industrial expectations. The framework consists of:

(1) Seven Positions: Corresponding to the occupational roles identified in the analysis, including debugging, integration, welding, vision, PLC development, maintenance, and application engineering.

(2) Four Core Abilities: Robot Maintenance and Repair Competency, Simulation Competency, Automated System Design Competency, and Automated On-Site Commissioning Competency.

(3) Seven Learning Modules: Each module corresponds to a position and is structured around specific competencies, teaching objectives, and assessment criteria.

This structure enables flexibility, as modules can be taught sequentially for comprehensive training or selected individually to target specific competencies. The modular design also allows rapid curriculum updates when industrial technologies or standards evolve.

4.3 Integration of Digital Technologies

To modernize the curriculum, digital technologies were embedded across all modules. Artificial intelligence (AI) tools were used to enhance automated feedback and personalized learning, particularly in programming tasks. Simulation platforms replicated industrial scenarios, enabling students to debug, test, and optimize robotic processes in safe, cost-effective virtual environments. Digital twin technologies provided real-time synchronization between virtual models and physical robots, bridging theoretical concepts with practical operations.

This integration of digital technologies not only reduces reliance on expensive hardware but also cultivates future-oriented competencies in students, preparing them for work in Industry 4.0 environments.

4.4 Case Example: Robotics Programming and Debugging

The pilot course Robotics Programming and Debugging illustrates the practical application of the modular curriculum framework. The course was designed as a core module targeting the competencies of debugging engineers and PLC developers.

(1) Course Objectives: To train students in robotic motion control, path programming, and system debugging techniques.

(2) Teaching Resources: Manuals, micro-lectures, and case libraries were supplemented with virtual simulation exercises.

(3) Implementation Approach: A dual-mentor model was employed, with school instructors delivering theoretical foundations and enterprise engineers guiding debugging exercises.

(4) Assessment: Both process-based evaluations (task performance, project completion) and outcome-based evaluations (knowledge tests, enterprise feedback) were used.

The success of this course confirmed the viability of the modular approach, demonstrating that integrating industry-based tasks, digital resources, and collaborative teaching can significantly improve students' practical skills and employability.

5. Smart Curriculum Resource Development

The effective implementation of a modular robotics curriculum requires not only well-designed course structures but also comprehensive and adaptive teaching resources. In line with the principles of digital transformation in education, this study emphasizes the creation of smart curriculum resources that integrate multimedia, simulation technologies, and AI-powered tools. These resources aim to bridge the gap between theory and practice while ensuring that students acquire competencies consistent with industrial expectations.

5.1 Design of Digital Learning Resources

Digital learning resources form the backbone of the modular curriculum. The study developed a set of structured teaching manuals that outline learning objectives, competencies, and practical tasks for each module. These manuals are complemented by micro-lectures—short video segments designed to explain key concepts such as robotic kinematics, PLC programming, and sensor calibration.

To enhance contextual learning, a case library was established containing enterprise-based scenarios, such as robot-assisted welding in manufacturing lines and automated sorting in logistics centers. Each case study is aligned with specific competencies, allowing students to directly connect classroom learning with real industrial practices. The modularity of these resources ensures that instructors can flexibly combine and adapt them according to course objectives and student needs.

5.2 Virtual Simulation and AI-Driven Teaching Assistants

Given the high costs and safety risks associated with physical robotics training, virtual simulation platforms were introduced as an essential component of the smart curriculum. These platforms replicate industrial environments where students can program, debug, and test robotic operations in a risk-free setting. Simulation tools allow for repeated practice and experimentation, significantly reducing dependency on expensive hardware.

In addition, AI-driven teaching assistants were integrated into the learning process. These digital assistants provide real-time feedback on programming exercises, offer step-by-step guidance during troubleshooting, and automatically generate diagnostic reports on student performance. This intelligent support system not only enhances personalized learning but also reduces the workload of instructors, enabling them to focus on higher-order mentoring tasks.

5.3 Development of Pilot Courses

Two pilot courses were developed and tested to validate the effectiveness of the smart curriculum design.

(1) Robotics Programming Debugging: This course introduces students to core skills in robot programming, motion path design, and system debugging. It employs digital manuals, case-based learning, and virtual simulation to simulate industrial debugging processes.

(2) Robotics Vision Sorting: This advanced course focuses on integrating machine vision with robotic systems to perform automated sorting tasks. Students engage in project-based assignments that combine image recognition algorithms with robotic manipulation.

Feedback from students and enterprise mentors demonstrated that these courses significantly improved both theoretical understanding and hands-on proficiency. Furthermore, the dual-mentor model ensured that industrial standards were embedded in teaching practices, reinforcing the practical relevance of the courses.

5.4 Dissemination and Continuous Updating Mechanisms

To ensure the sustainability of the smart curriculum, a dissemination and updating mechanism was established. All digital resources—including manuals, micro-lectures, simulation files, and AI-driven feedback systems—were compiled into an online repository accessible to students and instructors. This repository is designed to be scalable, allowing the integration of new case studies and updated simulation modules as industry technologies evolve.

A feedback loop was also introduced: student learning outcomes, enterprise evaluations, and faculty reflections are systematically collected and analyzed each semester. These data inform the iterative refinement of course content, ensuring continuous alignment with emerging industrial trends such as collaborative robotics, digital twin systems, and AI-enhanced automation. In this way, the smart curriculum remains dynamic, responsive, and future-oriented.

6. Implementation of School–Enterprise Collaborative Teaching

6.1 Dual-Mentor Mechanism: Roles of Academic and Enterprise Mentors

The implementation of the modular robotics curriculum was anchored in a dual-mentor system, where academic instructors and enterprise engineers worked collaboratively. Academic mentors were primarily responsible for theoretical instruction, course organization, and assessment design. They ensured that learning content aligned with educational standards and competency frameworks. Enterprise mentors, by contrast, brought in industrial expertise and were responsible for hands-on training, process troubleshooting, and the transfer of up-to-date industrial practices. This role division allowed students to benefit from both rigorous academic instruction and authentic workplace learning experiences.

6.2 "Four Real" Teaching Scenarios

To enhance authenticity and relevance, the teaching process was embedded within the "Four Real" scenario principle:

(1) Real Atmosphere: Learning environments simulated actual production settings, including enterprise workshops and robotics laboratories.

(2) Real Project: Students engaged in problem-driven assignments that mirrored industry tasks, such as programming robot arms for precision assembly.

(3) Real Role: Students assumed positions akin to enterprise engineers, such as debugging specialists or system integrators, thereby internalizing workplace responsibilities.

(4) Real Post: Training was aligned with actual job positions, creating a seamless transition between education and employment.

This immersive design strengthened students' professional identity and enhanced their readiness for industry demands.

6.3 Immersive Learning Pathways: "Admission Equals Employment"

The dual-mentor system and "Four Real" scenarios were combined into an immersive learning pathway summarized as "admission equals employment." From the moment students entered the program, they were treated as novice professionals integrated into industrial projects. This pathway emphasized early exposure to enterprise culture, consistent participation in project-based assignments, and gradual progression toward professional independence. By the time of graduation, students had accumulated both academic credits and verified workplace competencies, ensuring they were job-ready without additional transitional training.

6.4 Measured Outcomes of Collaborative Teaching Implementation

To evaluate the effectiveness of the collaborative teaching model, surveys, assessments, and enterprise feedback were collected. A comparative study was conducted between students trained under traditional models and those exposed to the dual-mentor, immersive pathway.

Table 6.1 Comparison of Student Learning Outcomes Before and After Implementation

Evaluation Dimension	Traditional Model (N=60)	Dual-Mentor Model (N=60)	Improvement (%)
Theoretical Knowledge Mastery	72.5	84.2	16.10%
Practical Operation Skills	68	88.6	30.30%
Problem-Solving Ability	70.3	83.7	19.00%
Enterprise Feedback Satisfaction	65.4	90.1	37.70%

The data reveal three key findings:

① Significant gains in practical skills: Students trained under the dual-mentor model demonstrated a 30.3% improvement in practical operation skills, confirming the value of enterprise-based instruction.

② Enhanced employability: Enterprise satisfaction scores increased by nearly 38%, suggesting that graduates are better prepared for immediate integration into the workforce.

③ Balanced competence development: Both theoretical mastery and problem-solving ability showed steady improvements, indicating that the collaborative teaching model achieves a balance between academic knowledge and applied competencies.

The comparative data highlight three important findings:

(1) Stronger Practical Proficiency—Students in the dual-mentor model demonstrated markedly higher operational skills, reflecting the value of enterprise-led training.

(2) Improved Problem-Solving—Exposure to authentic projects enhanced students' ability to diagnose issues and propose innovative solutions.

(3) Higher Industry Recognition—Enterprise satisfaction rates rose significantly, indicating that students trained under this model matched industry expectations more closely.

Together, these outcomes confirm that the collaborative teaching approach successfully bridges the gap between classroom education and industrial application, thereby fulfilling the objectives of the industry academy model.

7. Evaluation and Results

7.1 Framework for Multi-Dimensional Evaluation

To ensure a holistic understanding of the impact of the modular robotics curriculum, a multi-dimensional evaluation framework was established. This framework integrates perspectives from teachers, enterprise mentors, and students, allowing for both formative and summative assessments. Teachers provided feedback on knowledge delivery and resource effectiveness; enterprises contributed evaluations on practical competencies, employability, and workplace readiness; and students reflected on their learning experiences, engagement, and self-assessed skill acquisition.

The evaluation framework is structured across multiple layers, from external drivers to final outcomes, with continuous feedback loops ensuring iterative improvement. The conceptual design of this framework is summarized below.

Table 7.1 Conceptual Framework of Robotics Course Development and Implementation

Layer / Module	Key Components	Role in the Framework	Feedback Link
External Drivers & Context	• National/Regional Policies• Industry Demand• Certification Standards• Emerging Tech Trends	Provide policy support, define industrial needs, guide curriculum orientation	Feed into curriculum needs analysis
Curriculum Development	• Needs Analysis (job roles, tasks)• Competency Mapping (7 positions–skills)• Modular Framework (7 modules–4 abilities)• Resource Development (manuals, case libraries)	Translate industrial requirements into structured, competency-based curriculum	Adjusted based on evaluation outcomes
Digital Enablers	• AI Assistants for feedback• Virtual Simulation platforms• Digital Twin systems• Auto-scoring and analytics tools	Support flexible, cost-effective, and technology-driven teaching	Updated when new technologies emerge
Implementation	• Dual-Mentor Mechanism (academic + enterprise)• Shared Projects• "Four Real" Scenarios (atmosphere, project, role, post)• Immersive Pathway ("Admission = Employment")	Deliver curriculum through authentic, collaborative, industry-aligned teaching	Outcomes shape mentor training and scenario design
Evaluation & QA	• Multi-source Assessment (teachers, enterprises, peers, AI/sim data)• Indicators: knowledge, skills, problem-solving, employability	Ensure learning quality, monitor alignment with industry standards	Results feed back into curriculum revision
Outcomes & Impact	• Graduate Employability• Enterprise Satisfaction• Certification Alignment• Regional Talent Supply	Demonstrate effectiveness of curriculum and industry academy model	Provides data for continuous PDCA cycle

Continuous Feedback (PDCA)	• Curriculum updates• Mentor/faculty training• Module refresh• Policy tuning	Close the loop between outcomes and curriculum development	Connects back to Curriculum Development

The table highlights how different layers interact within the curriculum development and implementation process, and how evaluation results are fed back into curriculum revision, digital resource updates, and mentor training. This structure guarantees that the evaluation system is not static but dynamic, allowing for continuous optimization aligned with industrial and educational needs.

7.2 Effectiveness Analysis of Modular Robotics Courses

The implementation of the modular robotics curriculum, supported by smart resources and dual-mentor collaboration, demonstrated significant effectiveness in practice. Comparative results between traditional teaching and the new approach revealed measurable improvements in key learning outcomes:

(1) Knowledge Mastery: Students exhibited stronger conceptual understanding of robotics programming, system debugging, and integration, with average test scores increasing by over 10%.

(2) Practical Skills: Hands-on competencies, particularly in debugging and vision-based robotics tasks, improved markedly due to immersive training and simulation tools.

(3) Problem-Solving Abilities: Project-based assignments enhanced students' ability to tackle complex industrial problems, bridging the gap between classroom learning and workplace demands.

(4) Industry Recognition: Enterprise mentors reported higher satisfaction levels with students' workplace readiness, confirming that the curriculum aligned closely with real-world requirements.

These results validate the modular and competency-based design as a practical model for vocational education reform.

7.3 Limitations and Improvement Needs

Despite its effectiveness, the study identified several limitations that require future attention:

(1) Resource Dependency: The development of high-quality digital resources (e.g., simulation systems, AI-driven tools) demands significant investment. Institutions with limited funding may struggle to replicate this model.

(2) Faculty Training Gaps: While enterprise mentors contributed substantial expertise, some faculty members lacked sufficient industry experience, limiting the full potential of dual-mentor collaboration.

(3) Scalability Issues: The pilot implementation focused on two courses (Robotics Programming and Debugging and Robotics Vision Sorting). Expanding the framework to an entire program will require more systematic planning and resource allocation.

(4) Dynamic Updating Needs: With rapid advancements in robotics technologies, curricular content and digital resources must be continuously updated. A sustainable mechanism for technology scanning and curriculum refresh remains under development.

Overall, while the framework and implementation proved effective, long-term success depends on institutional support, scalable resource development, and stronger mechanisms for continuous renewal.

8, Discussion

8.1 Theoretical Contributions to Vocational Curriculum Development

This study contributes to the growing body of literature on vocational curriculum development in three significant ways. First, it provides a competency-oriented modular framework that operationalizes the principles of competency-based education (CBE) within robotics training. By mapping occupational roles to specific learning modules, the study demonstrates how vocational curricula can achieve greater alignment with industry-defined skills and tasks.

Second, the research expands the application of constructivist and work-process-oriented theories to the robotics domain. Through the integration of project-based learning, simulation, and dual-mentor guidance, students construct knowledge actively within authentic contexts. This reflects a shift from knowledge transmission to active engagement, bridging the gap between theoretical constructs and practical applications.

Finally, the study strengthens the argument for a systems-based approach to curriculum development, in which external drivers, curriculum design, digital technologies, collaborative implementation, and evaluation form a feedback-driven cycle. This systems perspective offers a replicable model that extends beyond robotics, potentially guiding reforms in other vocational disciplines facing rapid technological transformation.

8.2 Practical Value for Industry Academies and Regional Talent Cultivation

From a practical standpoint, the study demonstrates that industry academies can serve as effective platforms for workforce development in emerging sectors such as robotics and intelligent manufacturing. The dual-mentor model and "Four Real" teaching scenarios have shown to improve student readiness for industry, ensuring that graduates can transition seamlessly into professional roles.

For enterprises, the collaborative mechanism provides access to a pipeline of skilled workers who are familiar with enterprise processes and standards. This reduces onboarding costs and enhances workforce adaptability. For higher vocational colleges, the approach enriches teaching practices, diversifies learning resources, and strengthens institutional capacity for industry engagement.

At the regional level, particularly within the Chengdu–Chongqing economic zone, the integration of education and industry through modular robotics curricula contributes to regional talent cultivation. By aligning with local industrial strategies, the model supports not only student employability but also regional innovation capacity, helping to address skill shortages in advanced manufacturing clusters.

8.3 Challenges: Sustainability, Faculty Training, Enterprise Engagement

Despite these contributions, several challenges must be acknowledged. Sustainability remains a pressing issue. The development and maintenance of smart curriculum resources—such as AI-driven platforms and digital twin simulations—require significant financial and technical investment. Without continued institutional and governmental support, long-term sustainability may be compromised.

Faculty training is another critical challenge. While enterprise mentors provide valuable expertise, vocational faculty must also continuously update their knowledge of industrial practices. Structured professional development programs, industry placements, and collaborative research opportunities are needed to enhance faculty capacity.

Finally, enterprise engagement cannot be taken for granted. While initial collaboration was strong, enterprises may face competing priorities that limit their sustained involvement in curriculum development and teaching. Establishing incentive mechanisms—such as recognition systems, tax benefits, or shared intellectual property agreements—could help ensure enterprise commitment in the long run.

Taken together, these challenges highlight the need for a long-term, institutionally embedded strategy that balances innovation with resource management, ensures faculty-industry alignment, and maintains robust partnerships with enterprises.

9. Conclusion

9.1 Summary of Findings

This study examined the development and implementation of a modular robotics curriculum within the context of industry academy construction. By combining competency mapping, modular design, smart resource development, and school–enterprise collaboration, the research demonstrated that a curriculum grounded in industry needs can significantly enhance student learning outcomes. The introduction of the dual-mentor mechanism and “Four Real” teaching scenarios fostered stronger integration of theory and practice, while digital enablers such as simulation platforms and AI assistants expanded the scope and accessibility of training. Evaluation results confirmed improvements in knowledge mastery, practical skills, problem-solving ability, and enterprise satisfaction. Collectively, these findings validate the proposed framework as a replicable model for vocational education reform.

9.2 Implications for Higher Vocational Education Reform

The study offers several important implications for ongoing reforms in higher vocational education. First, it illustrates how competency-based modular curricula can be effectively operationalized to align with occupational standards and emerging industrial technologies. This approach addresses the longstanding mismatch between classroom learning and workplace requirements. Second, the findings highlight the value of industry academies as collaborative platforms for talent cultivation, resource sharing, and joint innovation. Through deep integration with enterprises, vocational colleges can provide students with authentic learning environments and pathways to employment. Third, the emphasis on smart curriculum resources demonstrates how digital transformation can overcome cost and safety constraints, making advanced robotics training scalable and sustainable. These implications suggest that vocational education reform should prioritize competency alignment, industry engagement, and digital integration.

9.3 Future Research Directions

While the study contributes both theoretical and practical insights, several avenues for future research remain. Further studies should expand the framework to a broader set of robotics and automation courses, testing scalability across different disciplines within intelligent manufacturing. Longitudinal research is needed to track graduate outcomes and career trajectories, providing evidence of long-term effectiveness in employability and career development. Additionally, comparative studies across regions and institutions could reveal how contextual differences influence the success of industry academy models. Finally, future research should explore the integration of emerging technologies—such as collaborative robots, industrial internet applications, and generative AI—into vocational curricula, ensuring that education continues to evolve in tandem with industry innovation.

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