

Knowledge Graph–Driven Modular Redesign: A Study of the Development Path for a High-Quality “Machine Vision Technology” Course in Higher Vocational Education

Chuanjing Guo*

Shandong polytechnic university, Weifang, Shandong, China

**Corresponding Author*

Abstract: As the "intelligent eyes" of smart manufacturing, machine vision technology plays a vital role in cultivating highly skilled professionals in visual inspection. In response to challenges in the current Machine Vision Technology course in higher vocational education, including superficial school–enterprise collaboration, a weak alignment between job requirements and course competencies, a lack of progressive course projects, fragmented integration of ideological and political education, and limited use of digital teaching methods, this study proposes a five-step approach guided by coordinated reform of key teaching elements. Centered on “knowledge graph–driven modular redesign,” the approach comprises building collaborative mechanisms, mapping competencies, restructuring the curriculum, integrating ideological and political education, and innovating teaching methods. Specifically, school–enterprise collaboration provides institutional support; a course competency graph links five key elements—programs, courses, textbooks, teachers, and practical training; progressively structured project modules are redesigned around work processes; professional ethics and technical skills are integrated into the curriculum; and AI agents and digital twin technology support a teaching model in which teachers, technology, and students interact and develop together. This study offers a measurable and transferable pathway for developing high-quality core courses in smart manufacturing programs at higher vocational institutions.

Keywords: Machine Vision Technology; High-Quality Course Development; Coordinated Reform of Teaching Elements; Course Competency Graph; Modular Redesign

1. Introduction

Machine vision, one of the most important frontier fields of artificial intelligence, is often described as the "intelligent eyes" of smart manufacturing. It is a key technology driving the digital and intelligent transformation of manufacturing [1].

At present, the teaching of "Machine Vision Technology" in higher vocational institutions faces several prominent challenges [2]. First, school–enterprise collaboration remains superficial and lacks an institutionalized co-development mechanism organized around the "three-group-leader system [3]." Second, course objectives are not systematically designed, resulting in a gap between the competencies taught and those required in the workplace. Third, course content is still organized primarily around disciplinary knowledge rather than authentic work processes. Fourth, professional qualities and technical skills are cultivated separately, leading to fragmented integration of ideological and political education into the course. Fifth, teaching remains dominated by conventional lectures, with insufficient use of AI and other intelligent teaching tools [4]. Against this backdrop, developing a high-quality "Machine Vision Technology" course through coordinated reform of teaching elements, with competency graphs guiding modular redesign, has become an urgent and important research topic.

2. Research Status and Problem Analysis

2.1 International Research

The industrial application of machine vision began relatively early outside China. Drawing on Industry 4.0 frameworks, countries such as Germany, Japan, and the United States have developed standardized training systems for machine vision professionals that align with the needs of smart manufacturing positions. Research in this area focuses on three main directions [5].

2.2 Domestic Research

The first concerns mechanisms for school-enterprise co-development: many institutions work with leading machine vision companies to develop courses and practical training facilities, establishing a basic division of responsibilities in talent cultivation [6]. The second concerns competency graphs and modular reform: researchers analyze occupational competencies, develop course graphs covering both knowledge and skills, and redesign project-based modules around systematic work processes [7]. The third concerns the integration of ideological and political education into machine vision courses, incorporating themes such as craftsmanship and workplace safety into engineering practice. The fourth concerns digital teaching reform, using virtual simulation and AI-based training platforms to improve hands-on instruction.

To address these gaps, this study uses the coordinated reform of key teaching elements as its theoretical framework and explores a systematic pathway for developing a high-quality course through graph-guided modular redesign.

3. Overall Design of the Development Path for a High-Quality "Machine Vision Technology" Course Based on "Graph-Guided Design and Modular Redesign"

3.1 Building the Foundation through Mechanisms: A Course Development Mechanism Based on Industry–Specialty Integration and School–Enterprise Collaboration

A course development team was established comprising enterprise engineers, full-time college teachers, and industry experts [7]. The team clarified the responsibilities and authorities of all parties in course development, thereby providing institutional support and industry-based input for curriculum reform. Relying on the pilot intelligent inspection workshop jointly established on campus by the university and Shandong Diehui Intelligent Technology Co., Ltd., the team conducted workplace-based investigations to examine the distribution of machine vision inspection positions, typical work tasks, and competency requirements in the regional smart manufacturing industry [8]. It also engaged in in-depth alignment with the actual production content and processes of leading enterprises in the industrial ecosystem of machine vision inspection, including the research and

development, production, and application of visual inspection systems [9]. Based on authentic industrial cases and enterprise occupational standards for positions such as visual inspection engineers, the university and enterprises jointly developed course teaching standards featuring "alignment between courses and job positions, integration of courses and practical training, integration of courses and vocational certificates, and project-based learning."

A collaborative course development mechanism was established based on the principles of "enterprises connecting workplace requirements with course design, colleges undertaking curriculum restructuring and implementation, and industry experts introducing industrial needs and setting standards [10]." The division of responsibilities and modes of collaboration were clarified across three stages: needs analysis, course development, and teaching implementation. Procedures for introducing enterprise resources and industry standards, together with a dynamic updating mechanism, were established to ensure that course content keeps pace with technological developments in industry. In this way, a closed-loop collaborative mechanism linking "industrial needs, course adjustment, and talent development" was formed [11].

3.2 Graph Deconstruction: Developing a Course Competency Graph Based on the Implementation of Visual Inspection Tasks and the Deconstruction of Competency Elements

Based on an analysis of the requirements of visual inspection positions, the "Machine Vision Technology" course competency graph was developed by systematically analyzing job responsibilities, breaking down process workflows layer by layer, and thoroughly deconstructing competency elements to reconstruct the knowledge and competency system. Through collaborative research conducted by the university and enterprises on talent development needs for machine vision inspection positions, the typical work content, tasks, and standards of such positions were systematically identified, and the core procedures and key stages of the work were extracted. In accordance with authentic work processes—including requirements analysis for machine vision inspection, solution design, system construction, image acquisition, preprocessing,

feature extraction, target detection, system commissioning, and delivery acceptance-work tasks and procedures were broken down step by step, with the operational content and quality standards covered by each task stage clearly defined.

The competencies and knowledge required for each process stage were deconstructed at three levels. The first level comprised competency domains, including visual system cognition and construction, image acquisition and processing, target detection and recognition, and system integration, commissioning, and optimization. By breaking down these competency elements, the competency requirements of relevant positions were clarified. The second level comprised knowledge modules. The knowledge points required to support the development of the competencies at the first level were analyzed, thereby establishing a course knowledge system that supports the coordinated development of competencies. The third level comprised practical support. Authentic workplace tasks and practical training environments were introduced, and competency and knowledge elements were incorporated step by step into the training process, thereby promoting effective coordination between course instruction and practical training.

3.3 Curriculum Redesign: A Project-Based Progressive and Task-Oriented Curriculum System Based on the Systematization of Work Processes

Following the logic of systematic work processes, the knowledge and competency system represented in the course competency graph was integrated with authentic workplace projects to redesign course projects and work tasks that align with both instructional requirements and occupational competencies [12]. Typical work tasks in the field of machine vision inspection were identified, including visual inspection solution design, light-source and camera selection and commissioning, image acquisition and preprocessing, target detection model training and optimization, and system integration and production-line commissioning. Each typical work task corresponds to a complete occupational action process, with clearly defined task objectives, work objects, working methods, task implementation procedures, and implementation assessment criteria [13].

Tasks with identical or similar work-process

characteristics were grouped into fields of action. These fields were then transformed into learning fields in accordance with occupational characteristics and the principles of teaching and learning. Complete machine vision production-scenario projects were designed on the basis of the learning fields, creating a progressive sequence that develops "from simple to complex and from foundational to comprehensive [13]." Foundational projects focus on training individual skills, intermediate projects emphasize the integration of multiple skills, and comprehensive projects focus on system integration and problem-solving [14].

Each project was further divided into several work tasks, with each task corresponding to a key stage in the systematic work process. For every task, implementation procedures were designed to specify the task objectives, supporting knowledge, skills training, task implementation, and implementation assessment [15]. In this way, a project- and task-oriented curriculum system based on authentic workplace tasks and guided by the course competency graph was developed.

3.4 Ideological and Political Empowerment: A Curriculum-Based Ideological and Political Education System Integrating Professional Qualities and Technical Skills

Ideological and political elements were deeply integrated into the specific characteristics of each project task. System thinking and an awareness of the bigger picture were incorporated into the task of "visual inspection solution design"; the spirit of craftsmanship and the pursuit of excellence were integrated into "light-source selection and commissioning"; and innovation awareness and critical thinking were incorporated into "inspection algorithm optimization." In addition, key stages of selected projects were designed to cultivate specific professional qualities. For example, the requirement that tasks be redone whenever accuracy fails to meet the specified standard was used to foster quality awareness, while completing tasks through teamwork was used to develop a spirit of collaboration. These measures enabled the organic integration of ideological and political education in a subtle and natural manner.

A curriculum-based ideological and political education framework was established encompassing "project tasks, skill components, professional quality requirements, ideological and political elements, integration methods, and

behavioral performance." This framework provides a systematic integration plan covering all course projects and running through every stage of instruction. It upgrades curriculum-based ideological and political education from fragmented incorporation to systematic design, transforms professional quality development from an additional component into an embedded element, and achieves the organic unity of knowledge transmission, competency development, and value formation.

3.5 Model Innovation: An AI-Enabled Interactive and Symbiotic Teaching Model Involving Teachers, AI, and Students

A course-specific AI agent was selected and developed for "Machine Vision Technology" to provide intelligent learning guidance, intelligent question answering, intelligent diagnosis, and intelligent recommendation. Based on students' learning profiles, the system can deliver personalized learning pathways and resources, accurately identify learning weaknesses, and recommend appropriately matched learning tasks and exercises.

A digital twin system for machine vision inspection was developed using authentic equipment and production-line data from the pilot workshop. The system supports virtual simulation operations, real-time data mapping, operational behavior tracking, and intelligent error-correction feedback. Students can conduct system construction and parameter-adjustment training in a virtual environment, while the system records their operational trajectories in real time and provides targeted guidance. The digital twin system creates a virtual replica of the physical production line, enabling students to rehearse production-line layout, robot programming, and PLC commissioning in a virtual space. The practical training platform covers intelligent production-line construction, process simulation, machine vision simulation, and dynamic data dashboards.

An interactive and symbiotic teaching model was established in which teachers, students, and an AI learning platform perform complementary functions. A classroom implementation process integrating "task-driven learning, AI-based resource delivery, behavior tracking, and immediate feedback" was designed. Learning-status analysis and personalized pre-study resources were incorporated before class; intelligent question answering was integrated into

classroom instruction; and personalized assignments, intelligent assessment, and learning profiles were incorporated into the entire post-class process. A pilot implementation was conducted with a practical training class in the pilot workshop. Throughout the process, data on student-AI interactions, classroom participation, learning behavior trajectories, and learning outcomes were collected, and the teaching model was optimized through data analysis.

Special attention should be paid to the possibility that automatic AI feedback may weaken students' independent troubleshooting and critical thinking, while reducing opportunities for hands-on discussion between teachers and students. Therefore, the logic of AI resource delivery should be calibrated against the course competency graph, a clearly defined human-AI division of labor should be incorporated into classroom procedures, and an intelligent evaluation system covering both technical skills and professional qualities should be established.

4. Practice and Effectiveness Validation of the High-Quality Course Development Path

This study selected two parallel classes from the smart manufacturing-related programs at Shandong Vocational University of Science and Technology as the subjects of a teaching reform pilot. The participants were two classes of 2025-entry higher vocational students majoring in smart manufacturing. The experimental class consisted of 28 students and received instruction in "Machine Vision Technology" using the high-quality course development approach of "graph-guided design and modular redesign." The control class consisted of 30 students and continued to follow the conventional discipline-based teaching model.

The course was delivered in the on-campus pilot intelligent inspection workshop jointly established by the university and Shandong Diehui Intelligent Technology Co., Ltd. The five-step development approach—"mechanism building, graph deconstruction, curriculum redesign, ideological and political empowerment, and model innovation"—was implemented in full. Based on the course competency graph, the reform involved the redesign of project-based modules, the systematic integration of ideological and political education, and the application of an AI agent and a digital twin teaching platform. The effectiveness of the reform was evaluated from multiple dimensions, including formative

assessment, practical skills assessment, course satisfaction, occupational adaptability, and professional quality development.

After a complete course cycle, teaching data were collected and comparatively analyzed from multiple perspectives. In terms of academic performance, the experimental class achieved an average theoretical assessment score of 84.7, compared with 77.2 for the control class. In the practical skills assessment, the task completion pass rate of the experimental class was 93.48%, compared with 81.82% for the control class. The experimental class demonstrated a particularly clear advantage in advanced competency tasks, such as system integration and commissioning and fault diagnosis in comprehensive projects. Formative assessment data also indicated significant increases in classroom task participation, practical training time on the platform, and the frequency of students' active questioning and discussion in the experimental class.

The course satisfaction survey showed that 91.3% of the students in the experimental class believed that the course projects closely reflected authentic workplace tasks in enterprises, while 89.1% recognized the contribution of the AI agent and digital twin practical training platform to hands-on learning. In addition, 86.9% of the students reported that they had developed an understanding of professional qualities such as quality awareness and the spirit of craftsmanship through practical training. Follow-up interviews with enterprise engineers showed that, in the view of industry experts, students trained under the reformed course had a more complete understanding of the workflow of machine vision positions and more practice-based project experience aligned with industrial settings. Their adaptation period after entering relevant positions was also shortened to some extent.

The implementation also revealed several limitations. First, some advanced comprehensive projects have high requirements for practical training hardware, and the in-depth integration of digital twin simulation with training on physical equipment requires further improvement. Second, the dynamic updating of the course competency graph requires sustained investment of human resources from both the university and enterprises, while the incentive mechanism for enterprise engineers to participate regularly in teaching remains inadequate. Third, the accuracy of the AI agent in answering open-ended fault

diagnosis questions in machine vision engineering still needs to be improved. More authentic industrial fault cases should therefore be continuously incorporated to optimize its knowledge base.

5. Conclusion

Machine vision technology is a core application technology in the field of smart manufacturing. Developing a high-quality "Machine Vision Technology" course in higher vocational education is an important vehicle for implementing the coordinated reform of key teaching elements in vocational education and cultivating highly skilled professionals specializing in machine vision inspection. In response to practical problems such as superficial school-enterprise co-development, weak alignment between occupational requirements and course competencies, the lack of progression among course projects, fragmented integration of ideological and political education, and superficial digital teaching reform, this study proposed "graph-guided design and modular redesign" as the core development approach. It established a five-step implementation pathway for high-quality course development: "mechanism building, graph deconstruction, curriculum redesign, ideological and political empowerment, and model innovation."

By establishing institutional safeguards for school-enterprise collaboration, the course competency graph was used as a hub linking the five key teaching elements of programs, courses, textbooks, teachers, and practical training. Progressive project-based course modules were redesigned according to the logic of systematic work processes. A curriculum-based ideological and political education system integrating professional qualities with technical skills was developed, and an interactive and symbiotic teaching model involving teachers, AI, and students was explored through the application of AI agents and digital twin technology.

Teaching practice demonstrated that this approach can effectively align course content with authentic workplace tasks, improve students' technical skills, engineering practice capabilities, and overall professional qualities, and provide a practical, measurable, and transferable reference for developing high-quality core courses in smart manufacturing programs within higher vocational education.

As vocational technologies continue to evolve at

an accelerated pace, future course development should further deepen industry–education collaboration, dynamically update and improve the course competency graph, strengthen the integration of virtual simulation and physical practical training, optimize the knowledge base of AI teaching agents for engineering scenarios, and improve long-term incentive mechanisms for the two-way participation of college and enterprise personnel in course development. Subsequent research will expand the scope of the pilot classes, continue to accumulate empirical teaching data, and further refine the course development approach to better meet the demand of the smart manufacturing industry for skilled professionals in machine vision technology.

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