Article

Teaching Reform of the Experimental and Practical Training Course "Fundamentals of Industrial Robot Technology" Using AI-Enabled and Project-Driven Instruction

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Abstract: Against the backdrop of the national New Engineering initiative, talent cultivation in intelligent manufacturing requires graduates who are interdisciplinary, engineering-oriented, and innovative. To address the prominent problems in the traditional experimental and practical training of the course "Fundamentals of Industrial Robot Technology" in application-oriented undergraduate universities, including outdated content, rigid teaching modes, and one-sided assessment, this paper leverages a university-enterprise collaborative education mechanism and integrates industrial robots, machine vision, PLC, and artificial intelligence to build an integrated experimental and practical training system driven by AI-enabled technologies and real enterprise engineering projects. Systematic reforms were implemented in three aspects: restructuring the experimental and practical content, redesigning the end-to-end teaching process, and establishing a diversified comprehensive assessment system. Comparative teaching practice was conducted across different classes in the same cohort. The results show that the reform significantly improved students' willingness to learn independently and their ability to solve complex engineering problems, and also led to markedly higher starting salaries and stronger employer recognition. The reform outcomes provide a practical reference for the experimental and practical training reform of intelligent manufacturing-related courses at local application-oriented universities.

Keywords: New Engineering; Industrial Robot; AI-Enabled; Project-Driven; Teaching Reform

1. Introduction

In 2017, the Ministry of Education of China fully launched the New Engineering initiative and released a series of guiding documents, namely the "Fudan Consensus", "Tianjin Action Plan" and "Beijing Guidelines". These documents set interdisciplinary integration, university-industry collaboration and continuous improvement as the core paths, aiming to cultivate high-quality engineering and technical talents with the capability to solve complex engineering problems [1]. On the one hand, the New Engineering initiative has boosted the establishment of emerging engineering majors such as intelligent construction and intelligent manufacturing [2]; on the other hand, it urges traditional mechanical and mechatronic majors to realize digital and intelligent teaching upgrading, break the barriers of single disciplines, and strengthen practical and innovative training [3].

Nowadays, the intelligent manufacturing industry is accelerating the integration of artificial intelligence, machine vision, industrial robots, automatic control and other multi-domain technologies. The industry keeps raising requirements for mechatronics graduates in comprehensive practical operation, project development and collaborative design [4]. Traditional experimental and practical training courses for industrial robots are limited to basic verification experiments such as robot body teaching and simple point-

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to-point motion. They lack comprehensive engineering training including AI-based visual sorting and automatic production-line integration, which leads to a prominent mismatch between talent output and enterprise job requirements.

As a regional application-oriented university, our university responds to the demands of local intelligent manufacturing industry. Taking the core experimental and practical training course "Fundamentals of Industrial Robot Technology" as the reform carrier, we jointly develop teaching resources with local intelligent-vision technology enterprises. Artificial intelligence technology, machine vision and PLC automatic control are integrated into the experimental and practical training system to build a closed-loop practical chain of "pre-class preparatory learning - in-class project practice - post-class enterprise on-the-job internship". The reform effect is verified through comparative teaching practice among different classes, so as to form a teaching reform path of experimental and practical training for industrial robot technology suitable for local application-oriented universities.

2. Limitations of the Traditional Experimental and Practical Training Model

Traditional experimental and practical training suffers from a narrow and outdated content structure, insufficient interdisciplinary integration, one-way lecturing, weak student agency, and one-sided assessment. As a result, practical competence is difficult to quantify, as shown in Figure 1.

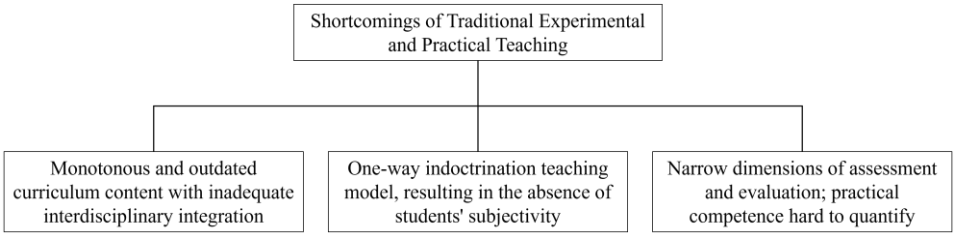


Figure 1. Limitations of the Traditional Experimental and Practical Training Model

2.1. Narrow and Outdated Content, with Insufficient Interdisciplinary Integration

The traditional content is dominated by demonstration and verification exercises, focusing only on robot teaching and simple trajectory programming. The curriculum has not been updated for years. It separates robot technology, vision inspection, and PLC control into disconnected units, and lacks integrated experimental and practical training projects. Emerging technologies such as AI vision recognition and intelligent sorting have not been introduced in time, so the content cannot match real smart-manufacturing production scenarios. Detached from actual industrial roles, the teaching content falls short of the New Engineering requirement to update resources in step with industry dynamics, leaving students with obvious gaps in comprehensive engineering training.

2.2. One-Way Lecturing, with Weak Student Agency

Current teaching still follows a fixed pattern of "teacher explains the principles, students reproduce the steps from the manual." This is a typical passive model. Students can complete the tasks by following standardized steps without understanding the underlying control logic or process design, which encourages perfunctory and superficial learning. The teaching process lacks open-ended design tasks, scheme evaluation, fault debugging, and optimization links, so it cannot train independent thinking, innovative design, or engineering debugging ability, nor can it effectively stimulate self-directed learning.

2.3. One-Sided Assessment, with Practical Competence Difficult to Quantify

The original final grade consisted only of the experiment/practical report (70%) plus classroom attendance (30%). The weighting was heavily biased toward written reports, while core practical links such as hands-on operation, project design, fault diagnosis, and

teamwork were excluded from assessment. The criteria were highly subjective and could not objectively distinguish students' operational level or engineering innovation ability. Under this single assessment mode, students focused on reports rather than hands-on work, and the learning goal was limited to finishing paperwork, which runs counter to the New Engineering emphasis on practical output and process-oriented assessment.

Traditional grading formula: S = S1 x 70% + S2 x 30%

Where S is the total score under the traditional model, S1 is the report score, and S2 is the attendance score.

3. Reform Plan Based on AI-Enabled and Project-Driven Teaching

In line with the New Engineering focus on outcomes and industry-education integration, we worked with a local smart-vision company to build teaching resources and integrated knowledge from robotics, machine vision, PLC, and artificial intelligence. On this basis, we developed a new experimental and practical training model centered on pre-class guided learning and enterprise engineering projects, and carried out reform across three dimensions, as shown in Figure 2.

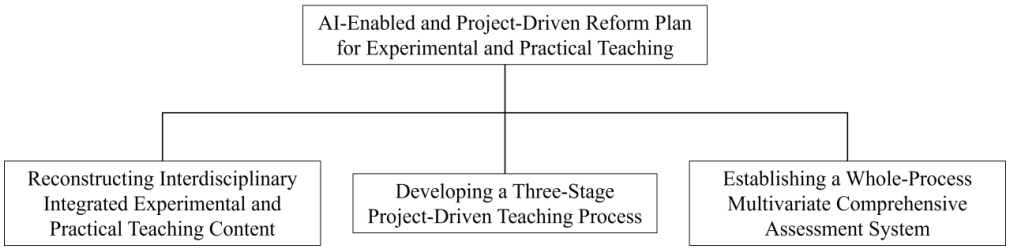


Figure 2. Reform Plan

3.1. Reconstruct Interdisciplinary Experimental and Practical Training Content

In response to the New Engineering requirement for interdisciplinary integration and deep industry-education collaboration [5], our university established a long-term collaborative education partnership with a local smart-vision equipment company in Dongguan. We moved beyond the traditional boundary in which the course only covered robot body operation, and built a four-in-one, tiered experimental and practical training system around real smart-manufacturing production scenarios, integrating industrial robot control, machine vision inspection, PLC logic linkage, and AI recognition. All projects are drawn from real production tasks on enterprise lines. We abandoned outdated, isolated verification experiments and instead designed modules in three layers, from basic cognition to integrated practice and innovative development, so that the teaching content can keep pace with the latest intelligent equipment technologies and compensate for the fragmentation and industrial disconnect of the traditional model.

3.1.1. Basic Cognition Layer: Standardized Robot-Body Experiments and Practical Training

This module is intended for the introductory stage of the course. It retains the necessary basic verification tasks, but the objectives have been redefined. The goal is no longer simply to observe motion results, but to strengthen the underlying operational logic of industrial robots and build a theoretical and operational foundation for later multi-technology integration projects.

The content includes coordinate system calibration for six-axis industrial robots (world, tool, and user coordinates), joint motion, linear motion, circular motion teaching programming, I/O port configuration, simple handling and positioning programming, robot fault-code identification, and basic equipment maintenance.

Compared with the traditional model, students are no longer asked to mechanically copy the steps in the manual. Each basic task is paired with a small reflective question, such as how to recalibrate the tool coordinate system after changing a fixture, or how to

troubleshoot an overtravel alarm step by step. This guides students to understand the control principles behind the operation, prevents shallow learning, and prepares them for the later vision- and PLC-linked exercises.

3.1.2. Integrated Layer: Robot-Vision-Control Production-Line Modules

This module is the core of the reform. It introduces mature enterprise projects as carriers, connects the three core technologies of robotics, vision systems, and PLC controllers, and designs two comprehensive production-line training projects, one for automatic protective-film application on wireless charging coils and one for vision-based labeling of chip packaging boxes, thereby reproducing the full process of a small automated workstation.

Experimental and practical training for the automatic film-application workstation for wireless charging coils

Overall process: material feeding -> AI vision positioning of coil pose -> robot gripping of the coil -> vision-based secondary position calibration -> robot completes protective-film application -> finished product unloading.

Students must complete full multi-device integration, including industrial camera intrinsic and extrinsic calibration, image feature extraction, communication between the vision coordinate system and the robot base coordinate system, PLC logic programming, robot grasping trajectory optimization, matching of film pressure and motion speed, and signal interfacing for loading and unloading limit sensors. The training is no longer split into separate lessons. Students are required to complete wiring, signal exchange, and program debugging independently and solve real engineering faults such as workstation lag, position offset, and film misalignment.

Experimental and practical training for the vision-based labeling workstation for chip packaging boxes

This project focuses on labeling processes in the electronics manufacturing industry and emphasizes barcode recognition, material sorting and positioning, and flexible robot gripping. The tasks include reading the QR code of the material by the vision system, issuing different motion commands through the PLC based on the recognition result, sorting qualified and unqualified products into separate bins by the robot, and synchronizing the labeling mechanism cylinder with the robot. Students must design the timing logic independently and handle common on-site problems such as misplaced materials and recognition failures caused by lighting interference. In this way, they develop an integrated control mindset in which machine vision provides perception, the PLC provides scheduling, and the robot provides execution.

3.1.3. Innovation Layer: AI Vision-Based Intelligent Sorting Extension Module

Using enterprise AI vision algorithm resources, we added advanced innovative design experiments and practical training to enable deeper AI empowerment for industrial robots, match the current digital transformation of intelligent manufacturing, and provide extension training for students who want to advance further.

The module is built around a small plastic-parts AI intelligent sorting workstation and consists of three parts:

1) AI dataset construction and model training: collect images of plastic workpieces with different colors and shapes, complete image annotation and dataset splitting, and use a lightweight vision algorithm to train an object-detection model that distinguishes good parts, missing-material parts, and deformed defective parts.

2) Hardware-software communication integration: deploy the trained AI recognition model on the vision industrial computer and establish Ethernet communication between the industrial computer, the robot, and the PLC so that recognition results can be issued in real time.

3) Independent design of innovative schemes: no fixed standard workflow is imposed. Students work in groups to design the sorting logic on their own, optimize the robot sorting path, add a defective-product return mechanism, or design a human-machine alarm interface. They are encouraged to propose differentiated solutions and

compare sorting efficiency, recognition accuracy, and equipment energy consumption, thereby producing a complete engineering optimization report.

3.1.4. Dynamic Update Mechanism for Experimental and Practical Training Content

To keep pace with industrial technology iteration, we established a dynamic update mechanism for jointly developed university-enterprise training resources:

1) Enterprise engineers visit the university each semester for technical seminars and synchronize the latest robot integration processes and new technologies in the 3C electronics and new energy sectors, with one to two comprehensive training projects updated every year.

2) The company provides retired or upgraded industrial cameras, servo controllers, robot end effectors, and other training hardware, aligned with mainstream industry equipment models, so that students do not train only on outdated equipment and then face a gap when they enter the workplace.

3) For emerging technical topics, we continuously expand lightweight digital-twin virtual training materials and integrate robot offline programming and digital-twin simulation debugging into pre-class learning resources. Offline physical training and online virtual simulation complement each other, enriching the dimensions of the experimental and practical training content.

The three-layer content system progresses from single-device operation to multi-disciplinary production-line integration and then to AI algorithm-based innovation. It fundamentally changes the isolation, single-technology orientation, and industrial disconnect of the traditional model. The entire process is guided by real enterprise process demands and systematically trains students in multi-technology integration, debugging of complex engineering problems, and project optimization, which is aligned with the goal of cultivating compound intelligent-manufacturing talent under the New Engineering initiative.

3.2. Build a Three-Stage Project-Driven Teaching Process

We established a full-cycle teaching process of "pre-class guided learning, in-class project implementation, and post-class enterprise extension training," supported by enterprise engineers teaching on campus and enterprise on-site training that breaks through the barriers between education and industry.

(1) Pre-class guided learning: distribute enterprise project process videos and technical documents, and invite enterprise engineers to explain the application scenarios and key technical challenges online and offline. Students are asked to organize the theory related to robotics, vision, and control in advance and to sketch a preliminary implementation plan, thereby stimulating active inquiry.

(2) In-class project implementation: students complete the engineering project in groups, with the instructor providing full-process guidance and enterprise engineers participating in scheme review. Students independently complete wiring, vision calibration, programming, and fault debugging, and troubleshoot production-line linkage problems themselves. The standardized replication of operation manuals is abandoned in favor of comparing and optimizing multiple schemes.

(3) Post-class sustained practice: after the course ends, the practice cycle continues. Students are organized to take part in short-term training at partner enterprises during spare time, winter vacation, and summer vacation. In the graduation stage, enterprise internship positions are arranged uniformly so that engineering operation ability can be continuously refined, forming a complete training loop from campus training to short-term enterprise practice and then to internship placement.

3.3. Establish a Diversified Comprehensive Assessment System

We moved away from a single evaluation model that overvalues reports and undervalues hands-on work, and built a three-dimensional assessment system consisting of attendance (10%), the full process of experimental design and operation (70%), and the experimental summary report (20%). The weights for project operation, scheme design,

and on-site debugging were increased so that students' engineering practice ability could be fully quantified.

Revised grading formula: S' = S1' x 10% + S2' x 70% + S3' x 20%

Where S' is the total experimental and practical training score after reform, S1' is the attendance score, S2' is the score for project scheme design, on-site operation, fault debugging, and teamwork, and S3' is the project summary report score.

The assessment focus shifted from written work to engineering operation and problem solving, improving objectivity and using assessment as a lever to push students to value practical training.

4. Implementation and Comparative Analysis of Teaching Effects

4.1. Study Participants

We selected students from the 2024 cohort majoring in Mechanical Design, Manufacturing and Automation, and Mechanical and Electronic Engineering at our university for a controlled teaching experiment:

Reform group (Class A): Mechanical Design classes 1-2 and Mechatronic Engineering class 1, taught with the new AI-enabled and project-driven model.

Control group (Class B): Mechanical Design classes 3-4 and Mechatronic Engineering class 2, taught with the traditional verification-based experimental and practical model. The teaching period, training equipment, and instructors were kept the same. The evaluation compared three indicators: students' willingness to learn independently, engineering practical ability, and starting salary after graduation.

4.2. Comparison of Reform Effects

The comparison in Table 1 shows that:

Table 1. Comparison of Implementation Effects between the Old and New Teaching Models

No.	Class	Teaching model	Initiative	Engineering practical ability	Salary level
1	Class A	New teaching model	98	95	8000
2	Class B	Traditional teaching model	70	75	4500

1. Learning initiative: driven by real engineering projects, the reform group showed a much stronger willingness to explore, and the proportion of students who previewed the material before class and extended their training after class increased substantially. Their initiative scores were significantly higher than those of the control group.

2. Engineering practical ability: integrated project training improved students' ability in equipment debugging, cross-technology integration, and fault diagnosis, increasing the practical ability score by 20 points.

3. Employment quality: students in the reform group had hands-on experience with integrated vision-robot projects that matched the needs of intelligent manufacturing enterprises. Their average starting salary increased by 3500 yuan compared with the control group, and enterprise recruitment feedback indicated stronger practical problem-solving ability and better job fit.

Overall, the practice demonstrates that this reform effectively implements the goal of cultivating compound talents under the New Engineering initiative and produces clear teaching outcomes.

5. Summary and Outlook

5.1. Reform Summary

The teaching model shifted from teacher-centered to student-centered

The pre-class guided learning and engineering-project-driven model fully opens up students' space for independent learning. It extends practical training to after-class time,

vacations, and enterprise internship stages, connects campus training to workplace capability, and continuously strengthens students' motivation for engineering innovation.

University-enterprise collaboration and AI-based multi-technology integration make up for the shortcomings of the traditional model

By introducing real enterprise production-line projects and integrating robotics, machine vision, PLC, and artificial intelligence, the reform addresses the disconnect between course content and industry. It systematically trains students in multi-disciplinary integrated design and complex engineering problem solving, thereby improving graduate employability.

The diversified full-process assessment system optimizes the evaluation orientation

By greatly increasing the weight of hands-on process assessment and taking into account scheme design, on-site debugging, and teamwork, the system more objectively reflects students' real engineering literacy and aligns with the outcome-based evaluation requirements of the New Engineering initiative.

5.2. Outlook

This reform was implemented only in one core experimental and practical training course. Future work can be expanded in three directions: first, build an online virtual simulation platform and combine digital-twin technology to enrich pre-class learning resources while reducing wear on physical equipment; second, develop cross-disciplinary joint experimental and practical projects that connect related majors such as automation and artificial intelligence; third, improve the long-term university-enterprise co-construction mechanism by jointly building industrial colleges and training bases, continuously updating frontier intelligent-manufacturing projects, and forming a replicable and promotable model for experimental and practical teaching reform in application-oriented undergraduate engineering education.

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