Research and Practice on Teaching Innovation of Experimental Courses for Electrical Engineering Majors from the Perspective of Industry-Education Integration

-- Taking the Practical Course of Electrical Control and PLC as an example

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Abstract

In view of the problems existing in the experimental courses of electrical engineering majors, such as insufficient connection between course content and industry, weak personalized support of teaching resources, and weak engineering practice orientation, an innovative experimental teaching system of "three-chain synergy, three-stage progression, and six-step guidance" is constructed based on the CDIO engineering education model and cognitive apprenticeship theory. By integrating the problem chain, resource chain, and mentor chain throughout the entire process of pre-class, in-class, and after-class, and through the hierarchical advancement of virtual simulation practice, hardware operation verification, and engineering innovation improvement, reconstruct the three-stage experimental content of "comprehensive design - engineering practice - innovative application", and create an integrated resource ecosystem of "digital twin + virtual simulation + cognitive apprenticeship", Establish a closed-loop evaluation system of "evaluation - feedback - improvement" that is data-driven, multi-collaborative, and ideological and political integrated. The curriculum is deeply integrated with elements of ideological and political education such as engineering ethics, craftsmanship, and patriotism, achieving a trinity of knowledge imparting, ability development, and value shaping. The teaching reform has significantly enhanced students' engineering practice, innovative design and job fit capabilities. In the past three years, students have won more than 30 national competition awards, 49 provincial-level and above innovation and entrepreneurship projects, and 63 authorized patents. The course has been recognized as a provincial first-class undergraduate course, a provincial model course for ideological and political education, and has received numerous honors such as the first prize of provincial teaching achievement and the second prize of teaching achievement of the Chinese Society of Simulation. The achievements have been promoted and applied in more than 20 majors within the university and more than 10 institutions within and outside the province, providing replicable and promotable practical models for the cultivation of high-quality technical and skilled talents in the field of intelligent manufacturing.

Keywords

Industry-education integration; Electrical control and PLC; Experimental teaching; Three-chain synergy; Three-step progression; Course-based ideological and Political education.

1. Introduction

"Electrical Control and PLC" is a core course for the major of Electrical Engineering and Automation (a provincial first-class undergraduate major construction point), which combines theory, practice and engineering, and is a key carrier connecting professional knowledge with industrial positions. Traditional experimental teaching, which is mainly based on verification experiments, has problems such as outdated content, single resources, disconnection from the intelligent manufacturing industry, low level of practical training, and insufficient cultivation of high-level capabilities, and is difficult to meet the demands of new engineering and regional industrial upgrading for compound engineering and technical talents[1][3]. To this end, this study, guided by industry-education integration and based on the reform of experimental courses, reconstructs teaching content, innovates teaching models, optimizes resource supply, and improves evaluation mechanisms to explore and form a set of experimental teaching innovation paths that are implementable, promotable, and replicable, comprehensively enhancing students' practical abilities, innovative thinking, and professional qualities.

2. The Current Situation and Pain Points of Curriculum Teaching

2.1. The curriculum content is not closely aligned with industry demands

The update of the curriculum lags behind the development of industrial automation and intelligent manufacturing technologies. There is a lack of cutting-edge elements such as real enterprise projects, intelligent production lines, and digital twins to support it. There is a gap between the knowledge system and the job competency requirements, and the cultivation of students' engineering application ability is insufficient (as shown in Figure 1).

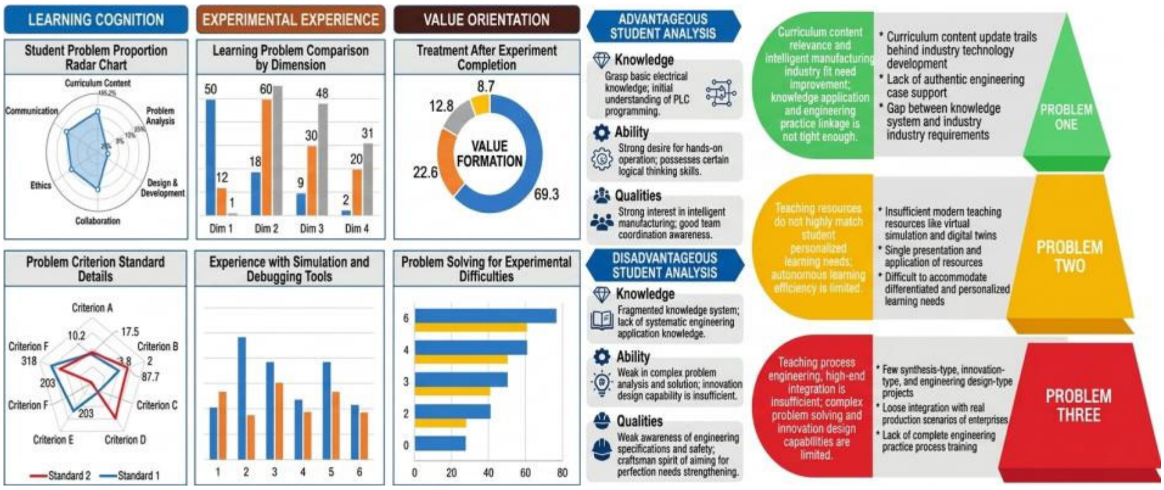


Figure 1. Analysis of Real Problems in the practical course

2.2. The mismatch between teaching resources and personalized learning is not high

The supply of modern teaching resources such as virtual simulation, digital twins, and online interaction is insufficient. The presentation methods of these resources are monotonous, making it difficult to meet the differentiated learning needs of students with different foundations and abilities, and the efficiency of autonomous learning is limited[2][7].

2.3. The process of experimental teaching is not engineered and advanced enough

Experimental teaching focuses more on operational verification, with fewer comprehensive, design-oriented and innovative projects. It is not closely integrated with the real production scenarios of enterprises, lacks complete engineering practice training, and has insufficient cultivation of complex problem-solving and innovative design capabilities.

2.4. The assessment and evaluation methods are monotonous and the education loop is incomplete

Traditional assessment is mainly result-oriented, with insufficient process-oriented, diversified, and value-added assessment, and inadequate examination of dimensions such as practical process, teamwork, engineering norms, and ideological and political literacy, making it difficult to achieve "teaching and learning through assessment".

3. Ideas and Concepts of Teaching Reform

Adhering to the core concepts of "student-centeredness, alignment with industry demands, strengthening engineering practice, and upholding moral education", with the integration of industry and education as the path and the improvement of experimental courses as the goal, an innovative teaching system of "three-chain synergy, three-stage progression, six-step guidance, and soul-shaping education" is constructed[3]. Through problem chain guidance, resource chain support, and mentor chain guidance, the entire process of pre-class - in-class - after-class guidance is achieved; Through virtual simulation practice, hardware hands-on verification, and engineering integration improvement, achieve hierarchical and progressive development of capabilities; Through the six steps of inspiration, guidance, analysis, practice, evaluation, and expansion, drive the transfer of knowledge to engineering capabilities; Through the deep integration of ideological and political elements, achieve the integration of value shaping, knowledge imparting and ability development, and ultimately cultivate high-quality applied electrical technology talents to meet the upgrading needs of the intelligent manufacturing industry (as shown in Figure 2).

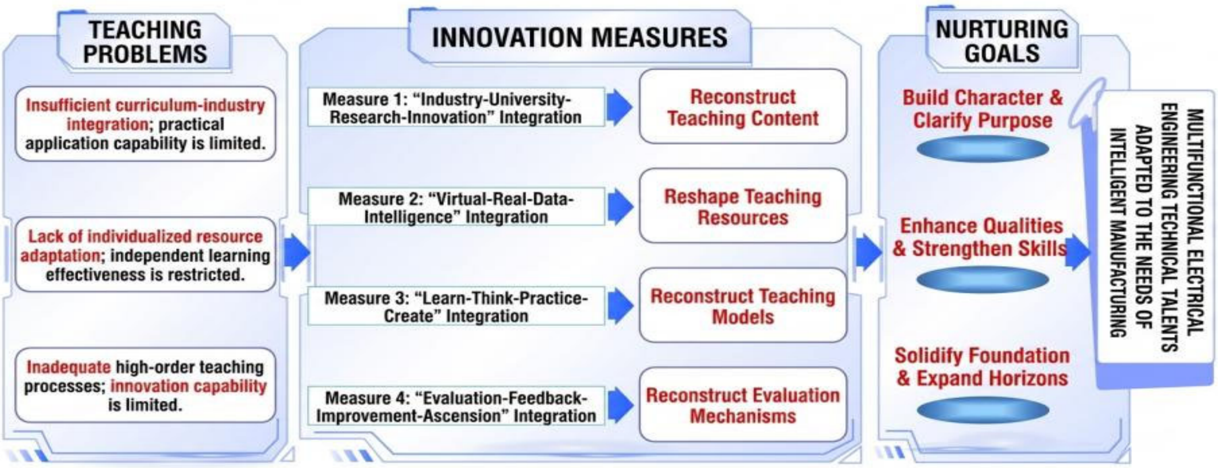


Figure 2. Teaching Innovation concepts and ideas

4. Reform Approaches and Methods

4.1. Reconstruct the experimental teaching content system

Based on industrial demands, real enterprise projects, scientific research achievements, and disciplinary competition cases, construct a three-stage progressive experimental content system of "comprehensive design - engineering practice - innovative application"

(1) Integrated design level: With typical equipment control as the carrier, strengthen basic programming, hardware wiring, and logical design capabilities;

(2) Use enterprise projects such as intelligent production lines, material sorting, and servo control as carriers to enhance multi-device linkage and system debugging capabilities;

(3) Use research and innovation topics such as energy-saving transformation, fault diagnosis, and intelligent monitoring as carriers to enhance the ability of scheme design and innovative optimization. Incorporate enterprise standards, engineering norms and safety procedures into the experimental content to achieve a "zero-distance" connection between experimental teaching and job requirements (as shown in Figure 3).

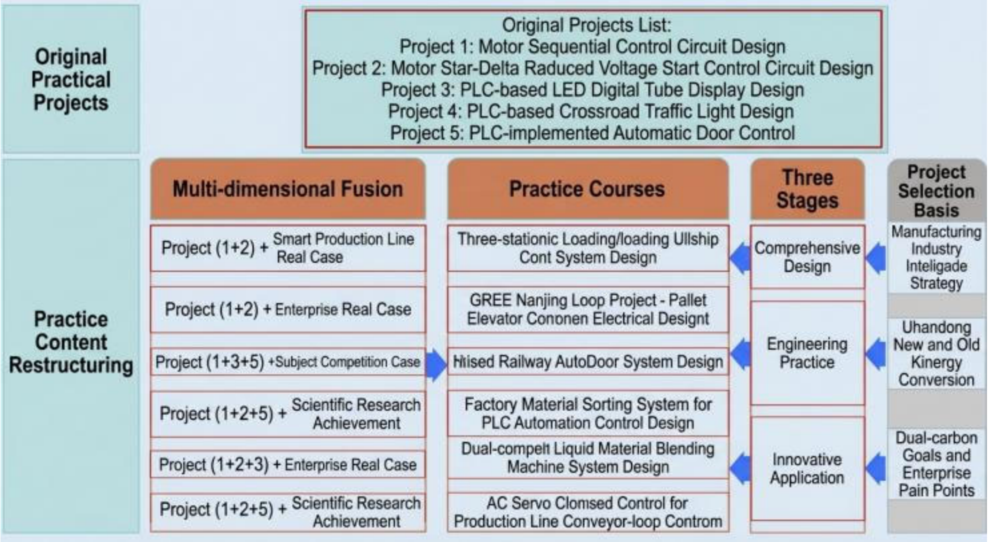


Figure 3. Reconstruction of Practical Course content

4.2. Innovate the teaching model of "three-chain synergy, three-stage progression, six-step guidance"(as shown in Figure 4)

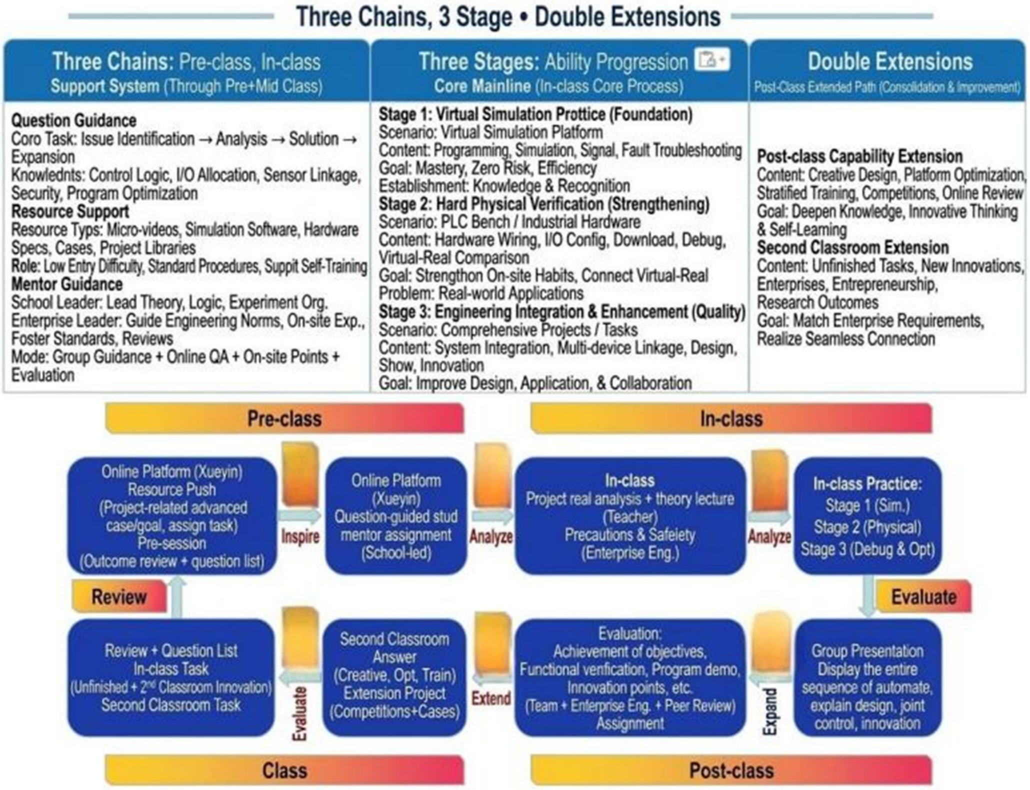


Figure 4. The whole-process education system

(1) Three-chain synergy:

Problem chain-guided learning: With engineering problems as the main thread, guide students to explore actively and solve step by step;

Resource chain support: Supported by micro-lessons, virtual simulations, enterprise cases, and digital twin resources to meet self-directed learning[6][10];

Mentorship chain guidance: In-school teachers and enterprise engineers provide collaborative guidance to achieve complementary theoretical and engineering experience.

(2) Three-step progression

Step 1: Virtual Simulation Practice: Zero-risk mastery of programming logic and control flow[5][10];

Hardware Practice Verification: Strengthening practical skills in wiring, debugging, troubleshooting;

Engineering Integration Enhancement: Complete comprehensive project design and system optimization.

(3) Six-step guided learning: Inspiration - guidance - analysis - practice - evaluation - expansion to achieve full-process capability development.

4.3. Build an integrated resource of "virtual and real integration, personalized adaptation"

Integrate resources such as the Intelligent Manufacturing Industry College, provincial model internship (training) base, Superstar Learning Pass, digital Twin platform, etc., to create:

(1) Virtual simulation + digital twin dual-track platform: Recreate the real production line scene and achieve "virtual programming - simulation debugging - twin verification" (as shown in Figure 5) [6];

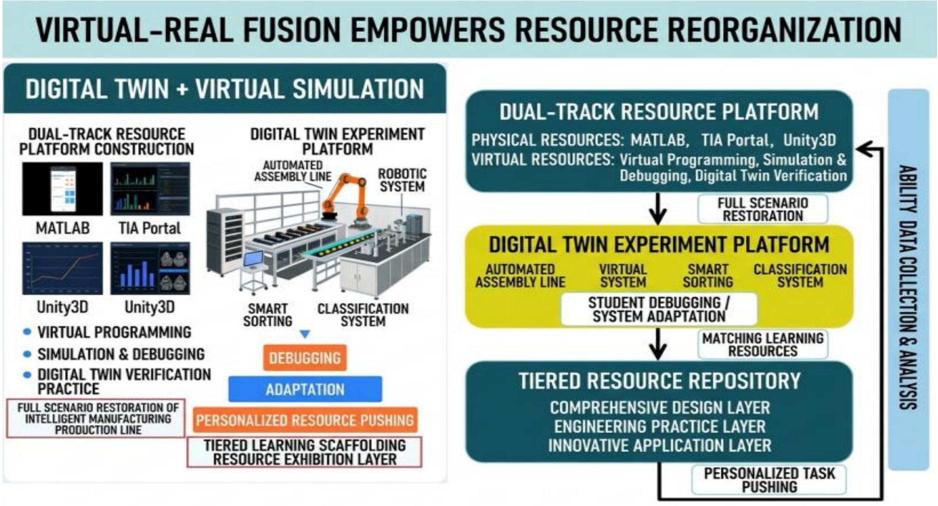
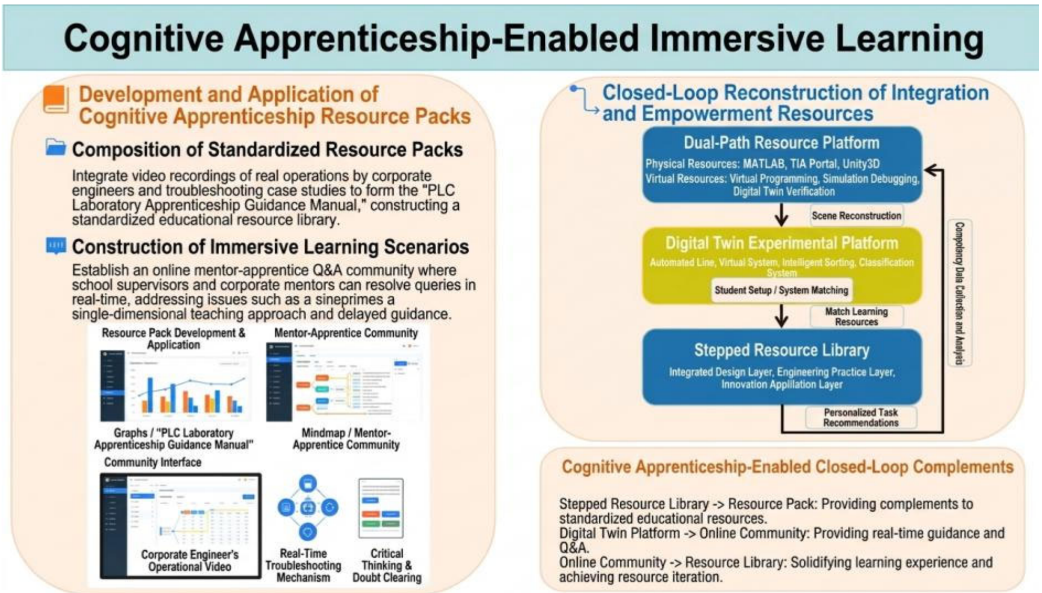


Figure 5. Virtual-real fusion empowers resource reorganization

(2) Stepwise resource library: Push basic, advanced and innovative resources hierarchically, build an innovative platform for talent cultivation, and achieve personalized and precise supply (as shown in Figure 6);

Figure 6. Talent Cultivation Innovation Platform

(3) Cognitive Apprenticeship Resource Package: It includes practical operation videos of enterprise engineers, fault cases, and guidance manuals, creating an immersive engineering learning environment (as shown in Figure 7) [4].


Cognitive Apprenticeship-Enabled Immersive Learning

Development and Application of Cognitive Apprenticeship Resource Packs

Composition of Standardized Resource Packs

Integrate video recordings of real operations by corporate engineers and troubleshooting case studies to form the "PLC Laboratory Apprenticeship Guidance Manual," constructing a standardized educational resource library.

Construction of Immersive Learning Scenarios

Establish an online mentor-apprentice Q&A community where school supervisors and corporate mentors can resolve queries in real-time, addressing issues such as a sineprimes a single-dimensional teaching approach and delayed guidance.

Cognitive Apprenticeship-Enabled Closed-Loop Complements

Stepped Resource Library -> Resource Pack: Providing complements to standardized educational resources.
Digital Twin Platform -> Online Community: Providing real-time guidance and Q&A.
Online Community -> Resource Library: Solidifying learning experience and achieving resource iteration.

Figure 7. Development of the Cognitive Apprenticeship Resource Package

4.4. Deeply integrate ideological and political education into the curriculum to achieve soul-casting and nurturing

Centering on the five ideological and political goals of ideals and beliefs, patriotism, engineering ethics, professional ethics, and craftsmanship spirit, explore ideological and political elements such as domestic PLC, engineering safety, green intelligent manufacturing, and science and technology for the country, and form a progressive ideological and political case chain [8]. Through "case introduction - reflection - tracking - extension - elevation", ideological and political education is naturally integrated into the entire process of experimental design, operation norms, team collaboration, and project debugging, achieving resonance between knowledge education and value guidance (as shown in Figure 8).

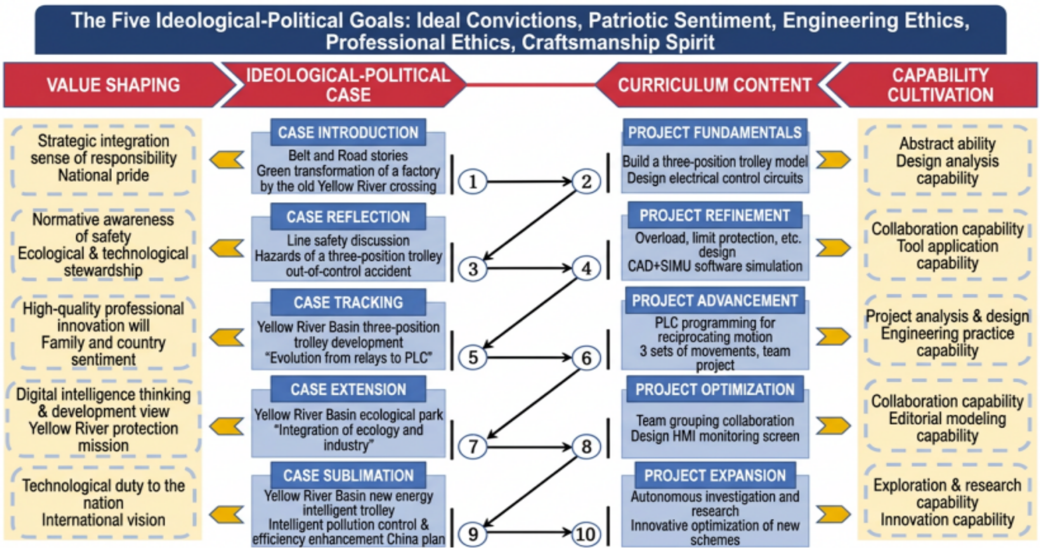


Figure 8. Project Case Integration of ideological and political Elements throughout the process

4.5. Establish a multi-loop evaluation mechanism to promote promotion through evaluation

Build a three-in-one evaluation system of process assessment + terminal assessment + value-added evaluation:

(1) Process evaluation: platform data, classroom performance, group collaboration, operational norms, ideological and political performance[9];

(2) Terminal evaluation: Project design, hardware wiring, program debugging, outcome presentation;

(3) Value-added evaluation: Innovation points, competition results, major innovation projects, patents, etc.

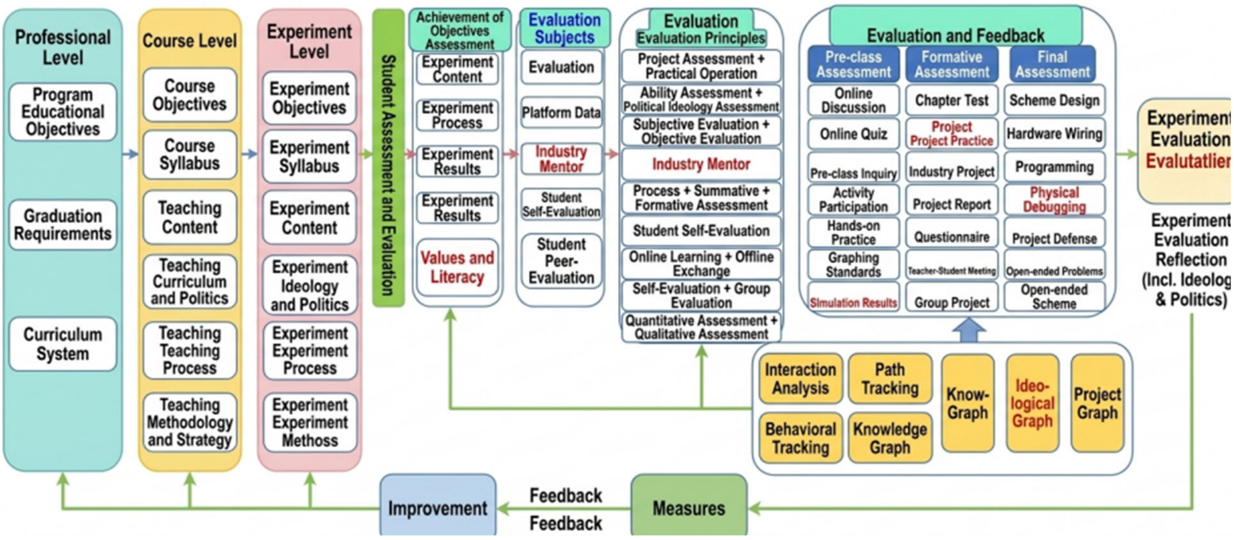


Figure 9. "Evaluation-feedback-improvement" closed-loop teaching quality evaluation mechanism

Establish the "evaluation-feedback-improvement" closed-loop mechanism, introduce multi-subject evaluation including enterprise mentors, on-campus supervisors, and student peer evaluation, and continuously optimize teaching (as shown in Figure 9).

5. Effectiveness of Curriculum Reform

5.1. Students' practical and innovative abilities have significantly improved

In the past three years, students have won more than 30 awards at the national level and 51 first prizes at the provincial level; 49 provincial-level or above innovation and entrepreneurship projects have been initiated; 63 patents have been granted. The employment competitiveness of students has significantly increased, and many graduates have grown into technical backbones of enterprises and have been highly recognized by employers.

5.2. The course construction has achieved fruitful results

The course has been successively approved as a provincial first-class undergraduate course and a provincial model course for ideological and political education. Won the first prize of provincial teaching Achievement, the second prize of Teaching achievement of Chinese Society of Simulation, and many other honors; Supported the establishment of provincial-level exemplary internship (training) bases and intelligent manufacturing industry colleges, and formed a batch of high-quality teaching resources and teaching cases.

5.3. The teaching model has been widely recognized

Student satisfaction is over 90%, and there is a significant increase in classroom engagement and learning satisfaction; The school supervisor's evaluation is consistently in the top 5%; Experts from the Electrical and Automation Teaching Steering Committee of the Ministry of Education gave high praise to the curriculum model, considering it to have demonstration and promotion value.

5.4. The demonstration and radiation effects are prominent

The reform achievements have been promoted and applied in more than 20 majors within the university, and have been exchanged and learned from in more than 10 institutions both within and outside the province, including Shandong University of Science and Technology and Jinan University. The relevant experience was reported by media outlets such as Guangming Daily; The team was invited to give special presentations at national teaching seminars, creating a good demonstration effect.

6. Conclusions

Based on the experimental course "Electrical Control and PLC (A)", this study, from the perspective of industry-education integration, systematically addressed prominent issues such as the disconnection between traditional experimental teaching and industry, single resources, and low practical level through content reconstruction, model innovation, resource upgrading, evaluation optimization, and integration of ideological and political education, and constructed a replicable and promotable innovative model of experimental teaching. The reform has achieved a shift from knowledge imparting to ability cultivation and value shaping, significantly improving the quality of talent cultivation and providing a useful reference and practical path for the reform of experimental teaching in electrical and related engineering disciplines in the context of new engineering.

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