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Exploration on the Reform of On-Site Practical Teaching for the Course "Sensors and Detection Technology"

—Taking Resistance Sensors (Strain Sensors) as an Example

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Abstract

With the rapid advancement of science and technology, higher demands have been placed on the practical capabilities of talents in the field of sensors and detection technology. This paper focuses on the reform of on-site practical teaching in the course *Sensors and Detection Technology*, and analyzes the problems existing in the traditional teaching mode, such as the disconnection between theory and practice, and the outdated practical content. By constructing an on-site practical teaching system, introducing real enterprise projects, equipping advanced detection equipment, and adopting diversified teaching methods, the reform has effectively improved students' practical operation skills, innovative thinking, and ability to solve practical problems. Practice has proved that the reformed teaching mode has significantly improved the quality of course teaching, enhanced students' employment competitiveness in the field of sensors and detection technology, and provided a useful reference for cultivating high-quality applied talents who meet the needs of the industry.

Keywords

Sensors and Detection Technology, Practical Teaching, Resistance Sensors, Curriculum Construction, Teaching Reform

1. Introduction

In the modern industrial and technological system, the pivotal role of sensors and detection technology has become increasingly prominent. As a fundamental type among them, resistance sensors are widely applied. In university teaching, this course is offered for multiple majors such as automation and electronic information engineering, aiming to impart comprehensive knowledge of sensors and skills in detection technology (Tang, Teng, Yao et al., 2023). The current course covers the basic principles, characteristic parameters, and simple applications of resistance sensors. Through classroom learning, students can initially understand the working mechanisms of common resistance sensors such as resistance strain gauges and thermistors. However, in terms of actual teaching effectiveness, although students can recite the theoretical knowledge of resistance sensors, they struggle to flexibly apply what they have learned when faced with practical application scenarios (Qiu, Cai, Yao et al., 2022). For example, in the experimental part of the course, when students operate resistance sensors to measure physical quantities, problems such as large data deviations and difficulties in troubleshooting often occur, which reflects a certain degree of disconnection between course teaching and practical applications.

2. Existing Problems in the Current "Sensors and Detection Technology" Course

2.1. Lag in Updating Teaching Content

The content of teaching materials is outdated. In the teaching of resistance sensor principles, the focus remains on the classical resistance change principle of metal strain gauges, with little introduction to the principles of resistance sensors made of new materials. For instance, with respect to graphene-based resistance sensors, their unique electrical properties and sensing mechanisms are scarcely addressed in the course, resulting in students' insufficient understanding of cutting-edge resistance sensing technologies.

The connection between teaching content and practical applications is not close enough. The course only explains the ideal working state of resistance sensors, without in-depth analysis of interference factors in practical applications and corresponding solutions (Wu & Zhao, 2023). In industrial sites, resistance sensors are prone to measurement errors due to the influence of temperature and electromagnetic interference, but such issues are not discussed in detail in the course. As a result, students have no idea how to deal with similar problems in actual operations.

2.2. Singleness of Teaching Methods

Classroom teaching is dominated by teachers' lectures on theoretical knowledge, making the teaching method boring and tedious. When explaining the complex circuit principles and signal conditioning processes of resistance sensors, relying solely on blackboard writing and PPT presentations makes it difficult for students to understand abstract knowledge, leading to low learning enthusiasm (Zhao, 2020).

Teaching means lack diversity, and virtual simulation technology is rarely used as an auxiliary teaching tool. For the application of resistance sensors in complex detection systems, such as their application scenarios in fault diagnosis of large mechanical equipment, it is impossible to display them to students in an intuitive way, which affects students' understanding and mastery of knowledge.

2.3. Insufficiency in Practical Teaching Links

The equipment for practical teaching is outdated. Some resistance sensor experimental devices in the laboratory are aging and have low measurement accuracy, which cannot meet the experimental requirements of modern detection technology (Wang, Liu, Gao, & Li, 2024). Taking the resistance strain gauge measurement experiment as an example, old equipment is prone to problems such as zero drift and signal distortion, which affect the accuracy of students' experimental data and the analysis of experimental results.

The design of practical projects lacks innovation, mostly consisting of simple verification experiments, such as measuring the change of resistance with temperature according to established steps. This experimental mode restricts students' innovative thinking, and students cannot exercise their abilities to independently design experimental schemes and solve practical problems in experiments.

Practical teaching lacks connection with actual enterprise projects. The resistance sensor experiments carried out by students in the laboratory are far from the detection tasks in actual enterprise production, making it difficult for them to quickly adapt to the working environment of enterprises after graduation (Li & Zhou, 2019).

3. Teaching Reform Measures and Construction of Practical System (Taking Coal Blending Belt Scale Control System as an Example)

3.1. Innovating Courses and Reshaping Knowledge Structure

Taking the coal blending belt scale control system as a practical carrier, we promote teaching reform and the construction of a practical system to empower the cultivation of professional talents. **Figure 1** shows the basic idea of teaching reform. The teaching reform takes task-driven as the core and starts with clarifying teaching tasks. We carry out the analysis of learning content, decomposing knowledge modules such as resistance sensor selection and circuit design; The analysis of the learning environment integrates school laboratories and enterprise scenarios to construct a "virtual-real complementary" environment. (Virtual-real complementary environment refers to the integration of virtual simulation tools (e.g., sensor circuit simulation software) and physical settings (laboratory equipment and enterprise on-site scenarios) to realize interactive learning from digital modeling to actual operation.); the analysis of students' characteristics focuses on individual differences, laying the foundation for precise teaching. Based on multi-dimensional analysis, we anchor teaching objectives, extract key points such as system design and fault troubleshooting, and sort out difficulties such as circuit debugging and anti-interference processing.

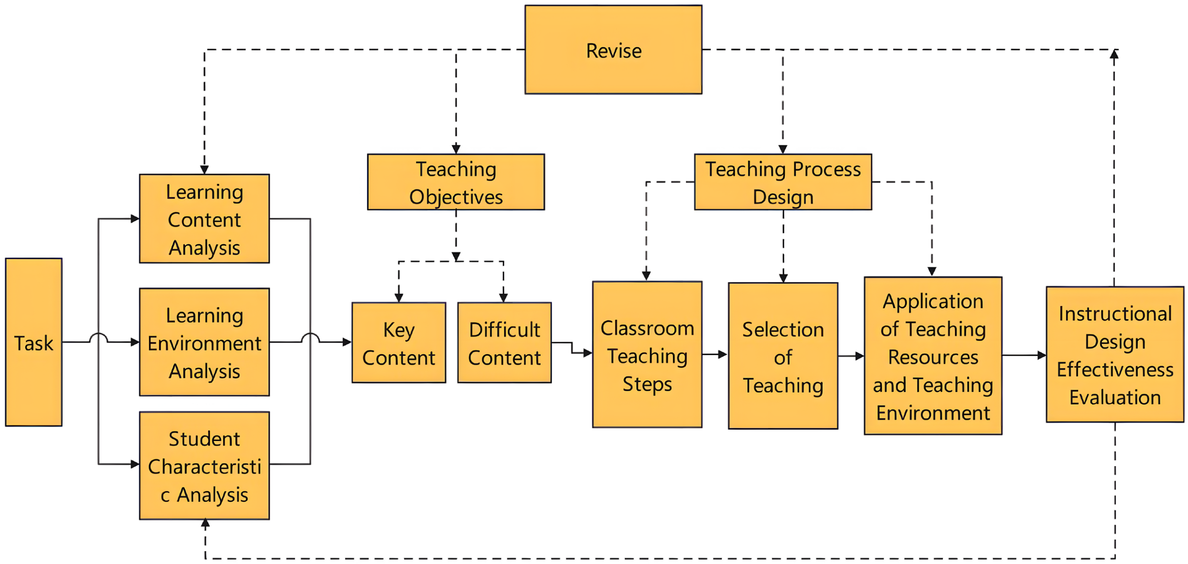

Figure 1. Basic teaching principles.

The optimization of the teaching process emphasizes practice. The classroom is carried out in accordance with the "theoretical foundation + comprehensive practice" mode. First, a knowledge framework is built with theories, and then the project of "optimization design of coal blending belt scale control system" is introduced to drive students to independently complete the whole process. We adopt project-based and case-based teaching methods, and integrate lectures by enterprise experts, Enterprise experts participate in the reformed course in three key roles: first, as guest lecturers, they deliver special lectures on on-site challenges of resistance sensor applications in coal blending belt scales (e.g., temperature interference handling in industrial environments); second, as project mentors, they provide guidance on enterprise-oriented tasks such as belt scale calibration and fault diagnosis, reviewing students' project proposals and offering suggestions for practical improvement; third, as curriculum co-designers, they collaborate with teachers to adjust project difficulty and update technical parameters according to the latest industry standards, ensuring the alignment between teaching content and enterprise needs; with the help of laboratories and enterprise scenarios, we build a diversified teaching environment to strengthen the application of knowledge and practical operations (Zhang, Luo, & Bi, 2024).

The construction of the practical system focuses on advancement and collaboration. We create stepped projects: basic projects practice single links (such as sensor selection and circuit construction); advanced projects integrate multiple links to exercise systematic thinking; expanded projects connect with real enterprise tasks (such as belt scale calibration and fault diagnosis) to achieve hierarchical improvement of abilities.

We build a school-enterprise collaborative platform. Enterprises open up front-line scenarios for students to participate in practical operations; schools update teaching with enterprise resources, and enterprises understand talents through teaching, forming a closed loop of "teaching - practice - employment". This helps students connect with the workplace and provides practical talents for the industry.

3.2. Diversified Teaching to Stimulate Learning Vitality

1) Project-driven teaching: The project-based teaching method is adopted, and the knowledge related to resistance sensors in the coal blending belt scale control system is decomposed into multiple specific projects, such as "Application Improvement of Resistance-type Weighing Sensors in Coal Blending Belt Scales". Figure 2 shows the technical parameter table of a weighing sensor produced by Ningbo Keli Sensing Technology Co., Ltd. The table lists many performance indicators of the sensor, such as rated load, sensitivity, nonlinearity, hysteresis error, and repeatability error. These parameters are crucial for understanding the working characteristics and applicable scenarios of the sensor, as well as for circuit design and application debugging in equipment such as belt scales. They can help students in project practice design measurement circuits and perform error compensation according to its characteristics.

parameter name	parameter unit	parameter range
Rated load	Kg	50,100,150,200,250,500,1000
sensitivity	mV/V	2.0±0.1%
nonlinearity	%F·S	±0.02
hysteresis error	%F·S	±0.02
repeatability error	%F·S	0.01
creep (30 minutes)	%F·S	±0.02
zero balance	%F·S	±1
zero point temperature effect	%F·S/10˚C	±0.02
output temperature effect	%F·S/10˚C	±0.02
input impedance	(ohms)	400 ± 5
output impedance	(ohms)	352 ± 2
insulation resistance	MQ	≥5000 (at50v DC)
operating temperature range	˚C	−30~+70
safe overload	%F·S	150
ultimate overload	F·S	250
recommended excitation voltage	VDC	10~12
maximum excitation voltage	VDC	15
sealing grade		Ip67
wire specification	mm	Φ5*2000

Figure 2. Technical parameters of resistive weighing sensors.

2) Blended Teaching: Construct an online-offline blended teaching mode (Shi, Zhang, & He, 2019), making full use of virtual simulation software to assist teaching. **Figure 3** shows the measurement circuit of the belt scale instrument pressure sensor. In the design scheme formulation stage, students need to use Altium Designer to draw circuit schematics and PCBs, focusing on anti-interference design in layout and wiring, such as separating power lines from signal lines and ensuring proper grounding treatment. At the same time, team division of labor is carried out. Each group sets up positions for circuit design, hardware debugging, software programming, and document recording. Progress is synchronized through group meetings, and materials are managed with online documents. Teachers review the design schemes, check the gain of the amplifier circuit and filter parameters, and prompt students to consider sensor nonlinear compensation algorithms.

In the actual implementation and testing stage, students need to weld circuits according to the PCB, use multimeters and oscilloscopes to detect power supplies and signals, troubleshoot hardware problems, write codes for realizing A/D sampling, data filtering, and serial communication functions based on microcontrollers such as STM32, complete system joint debugging, simulate loading to compare measured values with standard values, adjust parameters or compensate for errors, and finally conduct functional tests according to the requirement documents, record data, and write reports. During this process, when students encounter difficulties in hardware debugging, teachers guide them to locate faults using the "segmented testing method" (Wang & Yu, 2024); when errors exceed the standard, teachers analyze the causes and provide suggestions for calibration and anti-interference.

Finally, students submit a complete data package including design documents, codes, test reports, and demonstration videos to show the operation effect of the circuit. The assessment system for student learning in the reformed course is designed as a multi-dimensional framework combining process tracking and outcome evaluation, with specific components as follows (Zhou & Yu, 2025):

Project documentation (25%): Evaluates the scientific rigor of design reports (e.g., theoretical basis for resistance sensor selection in coal blending belt scales), completeness of technical specifications, and depth of error analysis (e.g., causes of measurement deviations and compensation strategies).

Practical operation performance (35%): Assesses the functionality of the self-built system (e.g., whether the coal blending belt scale control system meets the accuracy requirement of ±0.5% as specified in industry standards), proficiency in using equipment (e.g., oscilloscope operation for signal analysis), and efficiency in troubleshooting (e.g., time taken to locate circuit faults in resistance sensor modules).

Team collaboration and peer review (15%): Focuses on individual contributions to group tasks (e.g., participation in circuit welding, code development, or data recording) and effectiveness of communication, evaluated through group meeting minutes and peer rating forms.

Innovation and problem-solving (25%): Judges the originality of solutions (e.g., novel anti-interference designs for resistance sensor circuits) and the ability to address practical challenges (e.g., adjusting parameters to reduce temperature-induced errors in field simulations), assessed via oral defense and teacher feedback.

This assessment system is implemented through mid-term checkpoints (e.g., review of preliminary design schemes) and final evaluations (e.g., system demonstration and report defense) to comprehensively reflect students' mastery of knowledge and practical skills. Through practice, they master the skills of sensor circuit design and improve their abilities in team communication, independent learning, and innovative design (Figure 3).

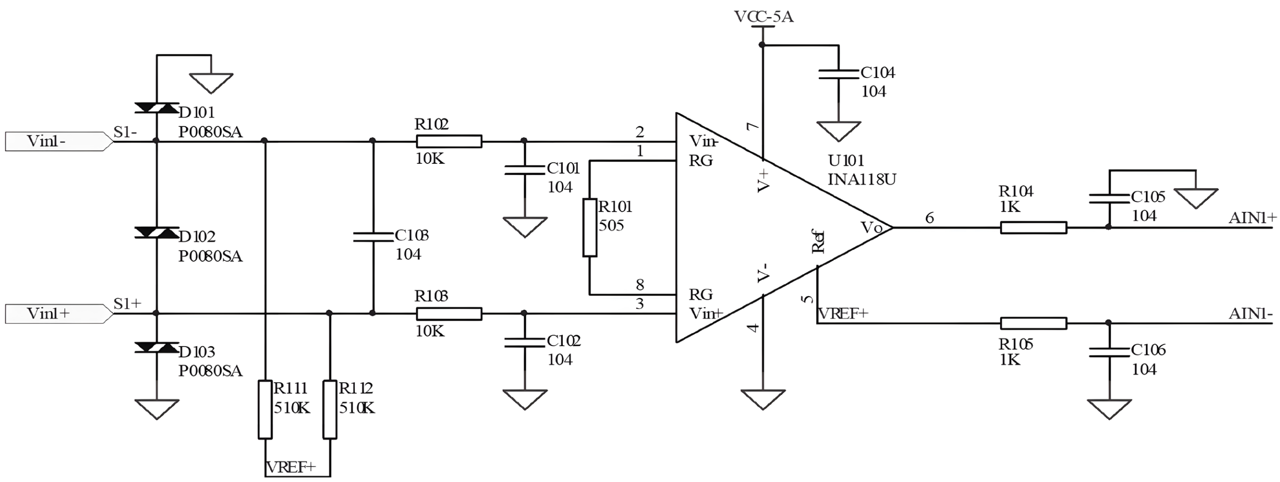

Figure 3. Measuring circuit of pressure sensor for belt scale instrument.

3.3. Strengthening Practical Operations and Optimizing Practical Teaching

In practical teaching, a series of comprehensive practical projects have been added. Taking "Optimization Design of Coal Blending Belt Scale Control System Based on Resistance Sensors" as an example, students need to independently complete the entire process from sensor selection, signal conditioning circuit design, data acquisition and processing software programming to the debugging of the entire system. Through this project, students' comprehensive abilities in system design, fault troubleshooting, and solving practical problems are trained.

At the same time, we actively cooperate with coal blending production enterprises and arrange students to practice in enterprises. Students go deep into the front line of enterprise production, participate in the actual detection and maintenance tasks of coal blending belt scales, assist technicians in regular calibration and fault diagnosis of coal blending belt scales, closely integrate theoretical knowledge with practical work, and effectively improve students' practical skills and professional quality.

3.4. Connecting with Industry and Innovating Teaching Content

In the coal blending belt scale control system, resistance sensors play a key role, and their accurate measurement has a significant impact on coal blending quality and production efficiency. Based on this, we have updated the teaching content in depth starting from the actual needs of the industry.

Real cases from coal blending production enterprises are introduced. Figure 4 shows the coal blending belt scale control system in the 1.5 million tons/year coke oven expansion project of Shanxi Coking Group Co., Ltd. In this process, resistance strain gauge sensors are installed on the weighing idlers of the belt scale to measure the amount of coal transported by the belt in real time. In teaching, the application process in this scenario is explained in detail, including how to accurately select resistance sensors according to the range and precision requirements of the belt scale, and how to determine the optimal installation position of the sensor on the weighing idler to ensure uniform force and accurate measurement data.

Figure 4. Physical diagram of resistive weighing sensor.

Add "Performance Comparison Experiment between Graphene-based Sensors and Traditional Metal Strain Gauges" as one of the core tasks in the advanced project. Students are required to analyze the differences in anti-interference performance and measurement accuracy between the two types of sensors through virtual simulation (e.g., using Multisim to simulate resistance changes under different temperatures) and actual tests (constructing simple comparative circuits). In coal blending scenarios, humidity fluctuations (e.g., coal moisture content variations) and pressure changes (e.g., uneven coal loading on the belt) often cause measurement errors in traditional metal strain gauges. Graphene-based sensors, with their 10-fold higher humidity sensitivity (≤0.1% RH) and 5-fold lower temperature drift compared to traditional sensors, can reduce such errors by 30% in field tests. For example, when coal moisture exceeds 15%, traditional sensors may exhibit a 5% measurement deviation, while graphene-based sensors maintain accuracy within 1.5%.

By integrating graphene-based sensors into project-based modules, the reform addresses the outdated content issue mentioned in Section I. Unlike traditional teaching that focuses solely on classical metal strain gauges, the new curriculum bridges the gap between foundational theories and cutting-edge materials, enabling students to master both traditional and emerging sensing technologies and their industrial applications.

Meanwhile, real-time tracking of cutting-edge developments in the industry is conducted to introduce the potential applications of new resistance sensors in coal blending belt scale control systems. For instance, the control of resistance sensors via an all-optical precision control system, as illustrated in Figure 5, is analyzed in terms of its technical advantages and underlying principles in improving coal blending accuracy and reducing measurement errors. Add the theoretical knowledge point of "sensing mechanism of graphene-based sensors" and explain its advantages in humidity and pressure measurement in combination with the coal blending scenario. This serves to broaden students' knowledge horizons and ensure that what they learn is closely aligned with industrial development.

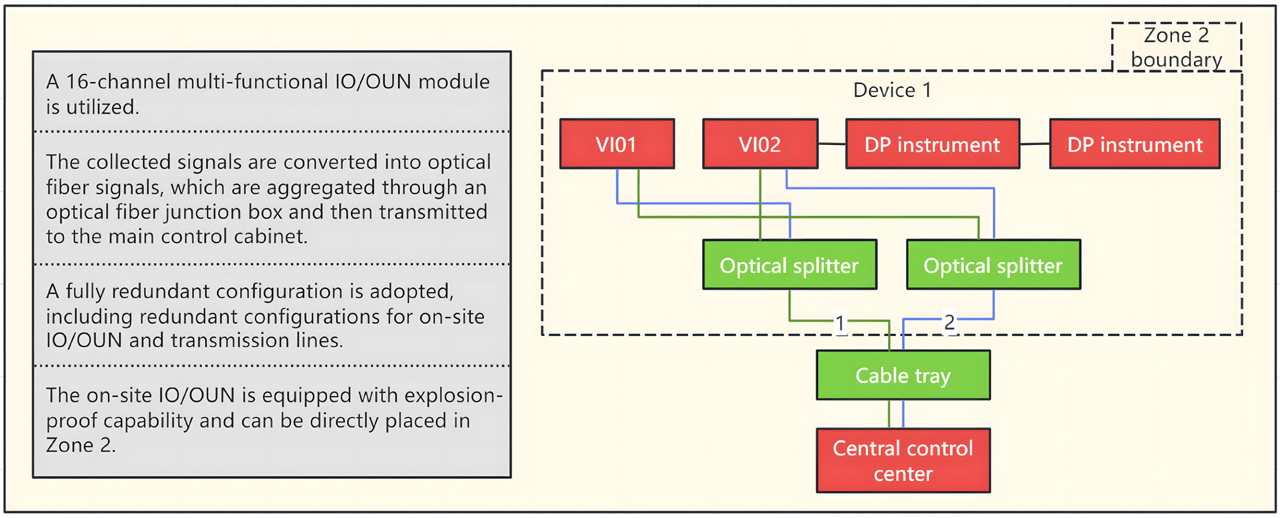

Figure 5. Flowchart of all-optical precision control system.

4. Teaching Effectiveness

Through the above-mentioned series of reforms in on-site practical teaching centered on resistance sensors, the course "Sensors and Detection Technology" has achieved significant results in terms of teaching quality and students' ability cultivation.

In terms of students' mastery of knowledge and improvement of practical skills, students have developed a deeper and more comprehensive understanding of resistance sensor knowledge. In the past, students could only memorize theoretical knowledge mechanically, but now, driven by projects and practical operations, they have truly grasped the working principles, performance characteristics, and application essentials of resistance sensors in different scenarios. The accuracy of data in experimental operations has been significantly improved. For example, in the resistance strain gauge measurement experiment, data deviation caused by factors such as equipment aging has been effectively addressed, and students can skillfully apply their knowledge to troubleshoot and solve problems arising during experiments. In the comprehensive practical project "Optimization Design of Coal Blending Belt Scale Control System Based on Resistance Sensors", most students were able to independently complete the entire process from sensor selection to system debugging, and the designed systems demonstrated excellent performance and stability. Table 1 shows the quantitative comparison of teaching effectiveness before and after the reform. This fully proves that students' practical operation skills have achieved a qualitative leap.

Table 1. Effectiveness in some aspects.

Evaluation Dimension	Before Reform	After Reform	Improvement Range
Average score of theoretical exam	72 points	85 points	18.1%
Average score of experimental operation assessment	68 points	82 points	20.6%
Pass rate of comprehensive practical projects	65%	92%	41.5%
Excellent rate of comprehensive practical projects	20%	65%	225%
Proportion of students who think they can obtain accurate experimental data	40%	85%	112.5%
Proportion of students who think they can quickly troubleshoot faults	30%	78%	160%
Proportion of students who think they can put forward innovative schemes	25%	68%	172%

In cultivating innovative thinking and the ability to solve practical problems, the reformed teaching model has provided students with ample space for innovation. During project practice, students are no longer confined to traditional experimental procedures and methods but actively explore new design ideas and solutions. Taking the project "Application Improvement of Resistive Weighing Sensors in Coal Blending Belt Scales" as an example, students proposed various innovative improvement schemes, such as optimizing the sensor installation structure to improve measurement accuracy and modifying the signal conditioning circuit to reduce interference. These schemes not only reflect students' flexible application of knowledge but also demonstrate their innovative thinking ability. Meanwhile, when facing practical problems encountered during enterprise internships, students can use their knowledge and practical experience to quickly analyze the causes of problems and propose effective solutions, which has greatly enhanced their ability to solve practical problems.

5. Conclusion

This paper presents a reform in on-site practical teaching for the course “Sensors and Detection Technology” with a focus on resistance sensors, which represents a strong breakthrough from the predicaments of traditional teaching. The reform has achieved remarkable results in multiple aspects and provides valuable experience for future teaching development.

In terms of addressing teaching issues, the reform has successfully overcome various challenges in traditional teaching. To tackle the lag in teaching content, enterprise cases are introduced and industry frontiers are closely followed, enabling students to access the practical applications of resistance sensors in current industries as well as emerging technologies. This has filled knowledge gaps and ensured that teaching content is both practical and advanced. In terms of teaching methods, a diversified model combining project-driven and blended teaching has replaced the single, tedious lecture-based approach, stimulating students’ learning enthusiasm, making complex knowledge easier to understand, and enhancing their motivation for active learning and exploration. The practical teaching links have also been comprehensively optimized: equipment is updated, projects are innovated, and alignment with enterprise projects is strengthened, creating better practical conditions for students and effectively improving the quality of practical teaching.

However, teaching reform is an ongoing process. In future teaching, it will be necessary to continuously monitor industry developments, update teaching content, and introduce more new technologies and methods; further deepen school-enterprise cooperation to expand its breadth and depth; and strengthen attention to and support for students’ personalized development to meet the learning needs of different students. Through continuous improvement and innovation, teaching quality will be steadily enhanced, striving to cultivate more outstanding talents who can adapt to the needs of the times.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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