The Design of Experimental Projects Based on the Integration of Science, Education, and Engineering for Energy and Power Majors under the "New Engineering" Background
—Taking "Calibration of Thermocouples and Temperature Measurement" as an Example

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Abstract: *The construction of the "New Engineering" requires universities to cultivate compound talents with practical abilities, innovative capabilities, and scientific literacy, with experimental teaching being a key aspect of achieving this goal. Currently, issues such as outdated teaching content, slow equipment updates, and monotonous teaching methods persist in university experimental teaching, resulting in insufficient student interest in experiments and limited hands-on opportunities. This paper integrates scientific research projects with experimental projects and adopts a project-based teaching approach to construct new experimental projects, aiming to incorporate cutting-edge technologies into experimental teaching, create authentic experimental scenarios, enhance student interest in learning, and provide more opportunities for hands-on practice. This paper provides certain reference value for experimental teaching reform.*

Keywords: *New Engineering; Integration of Science, Education, and Engineering; Project-based Teaching; Experimental Project Design*

1. Introduction

We are currently in the period of the Fourth Industrial Revolution, led by intelligent manufacturing. The demand for engineering and technology talents with innovation, entrepreneurship capabilities, and cross-disciplinary integration abilities is continually increasing. Innovation education has become the primary task of higher education in China today. In 2017, the Ministry of Education launched the "New Engineering" initiative, which focuses on "new concepts, new models, new quality, new methods, and new content" for building New Engineering. The construction of "New Engineering" aims to closely align with the societal demand for innovative, interdisciplinary talents. Experimental teaching serves as the bridge between theory and practice, the necessary path for connecting theory with reality, and plays an important role in cultivating students' experimental skills, independent exploration abilities, and scientific research capabilities. Promoting experimental teaching reform under the "New Engineering" background is a crucial aspect of achieving its construction goals and an important part of cultivating innovative, interdisciplinary talents. Therefore, the reform of experimental projects is an essential content in the teaching and research of talent development in the new era [1-4].

2. Issues in Experimental Teaching and Countermeasures

Experimental teaching in universities is an important part of cultivating students' practical abilities, innovation capabilities, and scientific literacy. However, there are still many issues in its actual implementation that affect teaching effectiveness and the quality of student development. The main problems currently existing in experimental teaching are:

2.1 Outdated Experimental Teaching Content, Disconnect from Frontier Disciplines, and Low Student Interest

The current experimental projects have remained unchanged for many years, with outdated content primarily focused on verification experiments. There are few comprehensive experimental projects, and experimental textbooks are updated slowly, failing to reflect the latest developments in industry technologies. As a result, students lose interest in experimental teaching.

2.2 Insufficient Experimental Equipment, Delayed Updates, and Decline in the Quality of Hands-on Skill Development

Due to constraints in laboratory space and funding, the quantity and quality of experimental equipment are insufficient and outdated. As a result, during experiments, the number of students per group is large (6-8 students per group), and more than half of the students are unable to engage in hands-on practice. Additionally, many instruments are old, resulting in low efficiency in experimental teaching.

2.3 Monotonous Teaching Models and Lack of Student Initiative

The teaching design and implementation do not give sufficient attention to the experimental teaching component, remaining focused on completing teaching tasks. The predominant "rote learning" teaching approach provides no room for student exploration. Teachers explain the steps in advance, and students mechanically imitate operations, resulting in insufficient development of students' independent abilities.

To address the above issues, the following countermeasures are proposed: The design of experimental teaching projects should shift from a "teacher-centered" approach to a "student-centered" approach. Utilizing existing experimental teaching resources, the design should focus on teaching objectives, use scientific research projects as the teaching context, and adopt a project-based teaching method. This approach aims to build experimental projects that integrate science, education, and engineering [5-9]. The main framework for constructing experimental projects is shown in Figure 1.

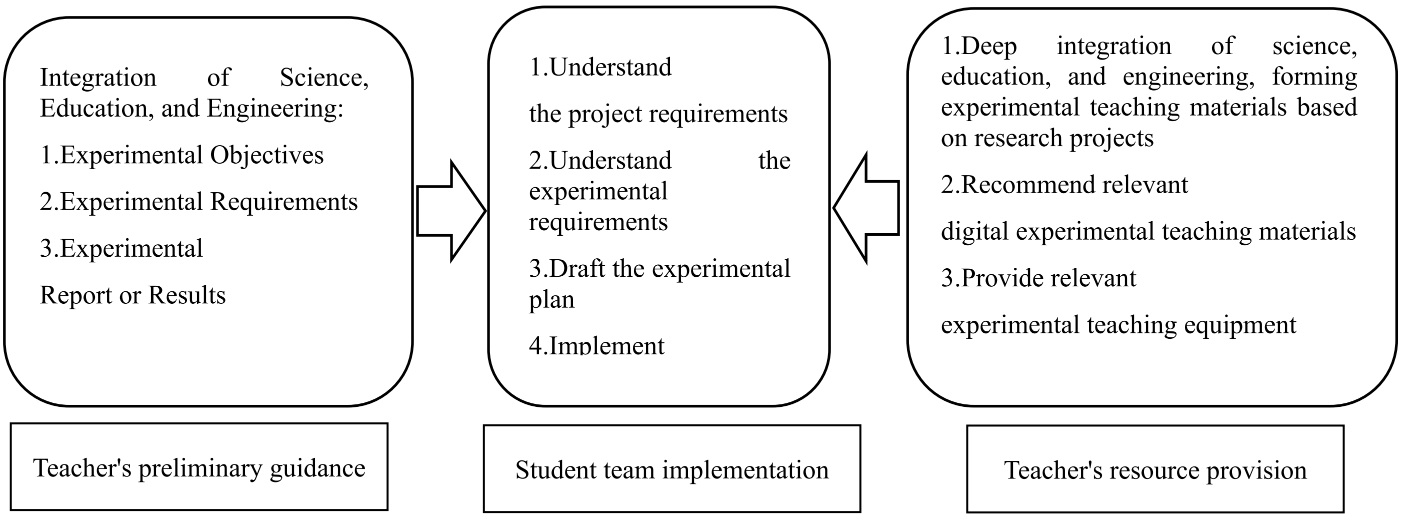

Figure 1. *Main Framework of Experimental Project Construction*

3. Experimental Project Design and Implementation

Based on the course "Power Engineering Testing Technology" for energy and power majors, and deeply integrating the horizontal research project "Key Technology Research of Solar Thermal Heat Pump Air Conditioning System," the experimental project "Calibration of Thermocouples and Temperature Measurement" is designed and developed.

3.1 Experimental Design

The experimental phase of the study on the performance of solar thermal heat pump air conditioning requires a large number of thermocouples, which must be calibrated and corrected before use. According to the teaching requirements of "Power Engineering Testing Technology," the performance testing of the heat pump air conditioning system in the research project is used as the teaching scenario to design the experimental project. The experimental design is divided into three stages: preliminary preparation, experimental plan determination, and experiment implementation.

3.2 Preliminary Experiment Preparation

The experiment will be conducted using a combination of classroom teaching and independent learning. A list of independent learning tasks will be developed, with the tasks complementing the theoretical teaching content. The aim is to enrich the teaching content through online resources (especially videos and animations), deepen students' understanding of the key points, expand their knowledge, and cultivate their independent learning abilities through proper guidance. The task list for the relevant knowledge preparation before the experiment is shown in Table 1.

Table 1. *Task List for Knowledge Preparation Before the Experiment*

Teacher's Guidance Points	Student Team Implementation Content	Guiding Materials
Principle of operation, working characteristics, and selection principles of thermocouples	Learn the principle of operation of thermocouples through online video resources, summarize the operating ranges and suitable applications of various types of thermocouples, and select the appropriate model	The "Seebeck" effect
Manufacturing, calibration, and correction of thermocouples	Learn the manufacturing, calibration, and correction processes of thermocouples through online video resources	Fanya Teaching Platform, thermocouple calibration experiment （https://mooc1.chaoxing.com/mooc-ans/nodedetailcontroller/visitnodedetail?courseId=87182092&knowledgeId=134700947）
Measurement of the evaporator refrigerant inlet and outlet temperatures of the heat pump air conditioner	Set temperature measurement points and familiarize with the use of the Keithley 6510 data acquisition instrument	Materials from the performance testing section of the "Key Technology Research of Solar Thermal Heat Pump Air Conditioning System" project GB/T 7725-2022

3.3 Determination of Experimental Plan

Based on the preliminary knowledge preparation, the student teams (4 members per team) will initially formulate the experimental plan, with the experimental objectives as the goal. The target requirements of the experimental plan are shown in Table 2. The student teams are required to complete the enrichment and refinement of each secondary objective according to the target requirements, which will be used as the final experimental report. After the experimental plan is confirmed by the supervising teacher, it will proceed to the implementation stage.

Table 2. *Detailed Experimental Plan Objectives*

Primary Objectives	Secondary Objectives	Target Requirements

Experimental Objectives	Thermocouple construction, working principle, and selection principles	
	Manufacturing and calibration of thermocouples	
	Measurement of the refrigerant inlet and outlet temperatures on the evaporator side of the air conditioner	
Experimental Steps	1. Selection of thermocouples	Determine the thermocouple model based on the working characteristics and measurement conditions of the thermocouple
	2. Manufacturing of T-type thermocouples	
	3. Calibration of T-type thermocouples	Calibrate using the comparison method and perform temperature correction using the digital compensation method
	4. Layout of temperature measurement points	Refer to the layout requirements for the temperature measurement points within the pipeline
	5.Testing of stable operating data under cooling conditions of the heat pump air conditioner	
Raw Data Recording		Automatically recorded by the data acquisition instrument
Experimental Data Processing		Perform vertical comparison of the raw data and eliminate data sets with measurement errors ≥ 0.5°C

3.4 Experimental Implementation

Using the "Key Technology Research of Solar Thermal Heat Pump Air Conditioning System" project experimental platform as the experimental teaching platform, the cutting-edge research in the discipline is demonstrated to students through the experimental testing platform. The project focuses on the fabrication, calibration, and temperature measurement of thermocouples, integrating key knowledge points related to thermocouples from the "Power Engineering Testing Technology" course with frontier scientific research projects. This approach not only achieves the goals of undergraduate experimental teaching but also incorporates cutting-edge research into the classroom.

3.4.1 Thermocouple Selection

Based on the working characteristics of various thermocouples, the operating temperature range of the heat pump air conditioner evaporator refrigerant, and the required experimental temperature measurement error, the thermocouple selected for this experiment is a T-type thermocouple.

3.4.2 Manufacturing of T-type Thermocouples

Copper wire and copper-nickel wire with a diameter of 0.1mm, a thermocouple spot welder, and protective goggles are provided for the student teams. During the preliminary preparation phase, the student teams independently manufacture the thermocouples in the laboratory. Once completed, the thermocouples are numbered according to student IDs for future use. This approach enhances students' sense of involvement, responsibility, and ownership.

Students use the TL-WELD (MES) type thermocouple welding machine to manufacture the thermocouples, as shown in the left image of Figure 2. The welded thermocouples are shown in the right image of Figure 2.

Figure 2. *TL-WELD Type Thermocouple Welding Machine and Self-made Thermocouple*

3.4.3 Calibration and Correction of T-type Thermocouples

The student teams will calibrate the self-made T-type thermocouples using the SY-3 thermocouple calibration system. The calibration is performed using the comparison method. The system includes a four-wire resistance thermometer, certified by the metrology department, which is used as the reference temperature measurement element. The calibration environment is a constant temperature water bath. Calibration process control requirements: Calibration temperature points are set at 5°C, 25°C, 45°C, 65°C, and 85°C. Five sets of measurements are taken at each temperature point. After the measurements, the average temperature readings from the self-made thermocouples at each temperature point are used to calculate the measurement error. If the maximum measurement error is ≤ 0.5°C, the self-made thermocouple can be directly used. If the measurement error is > 0.5°C, the digital compensation method is applied to correct the thermocouples. Using the correction formula, the key parameters a and b for each thermocouple needing correction are determined, preparing for the next measurement phase.

The SY-3 thermocouple calibration system is shown in Figure 3.

Figure 3. *SY-3 Thermocouple Calibration System*

3.4.4 Experimental Implementation

The thermocouple temperature measurement work is carried out on the experimental platform of the "Key Technology Research of Solar Thermal Heat Pump Air Conditioning System" project. According to the temperature measurement point layout positions in the above experimental report, the working ends of the thermocouples are placed tightly against the inlet and outlet pipe walls of the air conditioner evaporator. The thermocouples are then securely fixed using paper tape and insulated with rubber and plastic for thermal insulation. The cold ends of the thermocouples are connected to the mV signal channels on the Keithley data acquisition board. When connecting, the copper end is connected to the high potential point of the signal channel, and the copper-nickel end is connected to the low potential point of the signal channel. Since the Keithley 6510 data acquisition board has integrated cold junction temperature compensation in the signal input channels, no additional cold junction temperature compensation is needed during the temperature measurement.

Under this premise, thermocouples that require digital compensation correction during the calibration and correction phase only need to be corrected in the data acquisition software by adjusting the corresponding channels. Specifically, the values of correction parameters a and b in the respective channels should be modified to the a and b values calculated during the calibration and correction phase, enabling accurate temperature measurement. The data acquisition frequency of the Keithley 6510 is set to 1 reading per minute.

After completing the above work, the solar thermal heat pump air conditioning experimental platform is turned on, and the operating condition is adjusted to the cooling mode. Once the operating condition stabilizes, the Keithley data acquisition instrument is started to continuously measure the inlet and outlet temperatures of the evaporator for 20 minutes. The measurement results are automatically saved in the corresponding Excel file, which serves as the raw experimental data.

The overall experimental platform used for the experimental teaching portion of the "Key Technology Research of Solar Thermal Heat Pump Air Conditioning System" project is shown in the left image of Figure 4, and the physical layout of the thermocouples at the evaporator inlet and outlet is shown in the right image of Figure 4.

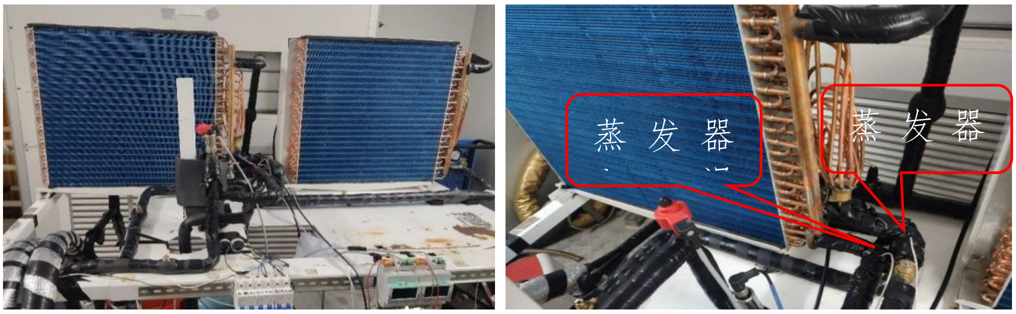

Figure 4. *Overview of the Experimental Platform and Temperature Measurement Points Layout*

3.4.5 Data Processing

The raw data from this experiment will be used as the raw data for the performance test of the air conditioning cooling mode and is not part of the current experimental task. Therefore, only data cleaning is performed on the raw experimental data. Among the 20 sets of evaporator inlet and outlet temperature data, arrays where the temperature values of the inlet and outlet deviate from their respective averages by > 0.5°C are identified as outliers and removed. The remaining data sets are considered valid data and can be used for other experiments.

Conclusion

The completion of the experimental testing project enabled students to master the methods of thermocouple fabrication, calibration, and temperature measurement through a specific task. The experiment guided students to learn the method of generalizing knowledge points, with each student deeply involved in the experiment, resulting in a significant improvement in their hands-on skills. The implementation of the experiment increased students' interest in the major and enhanced their personal confidence.

The reasonable integration of "Thermocouple Calibration and Temperature Measurement" with the "Key Technology Research of Solar Thermal Heat Pump Air Conditioning System" research project showcased cutting-edge research to students through the experimental platform, transforming abstract theoretical concepts into contextualized, visualized scenarios, thus enhancing student interest in learning. By focusing on thermocouple fabrication, calibration, and temperature measurement, key knowledge points from the thermocouple section of the "Power Engineering Testing Technology" course were deeply integrated with cutting-edge research projects. This not only achieved the goals of undergraduate experimental teaching but also incorporated frontier research into the classroom.

The experiment addressed the issue of outdated traditional experimental teaching equipment by updating the content and improving the utilization of scientific research instruments and equipment. By appropriately scheduling experimental time, the barriers of space and time constraints in traditional experimental teaching were overcome, optimizing the use of existing experimental teaching resources. The design and implementation methods of this experimental project provide valuable insights for the reform of experimental teaching.

Funded Project

Research and Practice Project on Research-based Teaching Reform in Undergraduate Universities of

Henan Province: Research-based Teaching Reform and Practice for Energy and Power Majors Based on the Ecological Chain Model under the New Engineering Background

References

[1] Kong, X., Lu, H., Liu, C., & Wu, Z. (2022). Exploration of the construction of intelligent building laboratories in universities under the "New Engineering" background. Laboratory Research and Exploration, 41(12), 281-285.

[2] Ye, X., Chen, G., Cheng, X., Zhu, C., Xing, W., & Wang, X. (2023). Reform and practice of practical teaching bases for energy and power majors under the "New Engineering" background. Research in Higher Engineering Education, SI, 53-56.

[3] Shi, S., Li, H., Zhao, X., Zheng, B., & Xu, X. (2023). Reform and exploration of electronic packaging technology experimental teaching based on the "New Engineering" model. Experimental Technology and Management, 40(SI), 29-33.

[4] Wang, Y., Zhang, H., Huang, J., Li, H., & Peng, H. (2023). Design of experimental cases based on human posture perception information for the "New Engineering" curriculum. Experimental Technology and Management, 40(3), 217-225.

[5] Wang, G., Hu, Z., Tao, Y., Li, W., Yang, S., & Zhang, J. (2025). Design of teaching experiments for controlling mechanical hands based on brain-computer interfaces. Experimental Technology and Management, 42(5), 186-191.

[6] Yang, Z. (2024). Research on computer teaching reform methods based on project-based teaching. Mechanical Design, 41(12), 158-162.

[7] Cai, X., Xu, J., & Dong, Y. (2022). Construction of teaching models for applied talent cultivation in vocational colleges based on project-based teaching methods. Vocational and Technical Education, 43(23), 47-51.

[8] Yao, Y., Yu, M., Chen, S., Yang, Z., Zhang, D., & Xu, C. (2019). Project-based teaching method-driven reform and practice in graduate courses: A case study of the "Chemical Engineering Design and Process Optimization" course. Chemical Education (Chinese and English), 40(22), 69-73.

[9] Tian, W., Zou, B., Song, Y., Liu, W., & Wang, M. (2021). Application of project-based teaching method in undergraduate experimental teaching in universities. Chinese Veterinary Journal, 57(12), 119-122.