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# *Teaching Reform of Principles of Electrochemistry in New Energy Science and Engineering: A Case Study of Shandong Institute of Petroleum and Chemical Technology*

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***Abstract:*** With the acceleration of global energy transition and the vigorous development of the new energy industry, the Principles of Electrochemistry, as the core course for the major of New Energy Science and Engineering, urgently need to be reformed to meet the demands of the industry for high-quality applied talents. Taking Shandong Institute of Petroleum and Chemical Technology as an example, this paper addresses the problems of disconnection between theory and practice and outdated content in traditional electrochemistry teaching. Based on the concept of industry-education integration and the OBE philosophy, a three-dimensional course objective system of “knowledge - ability – quality” has been constructed. A modularized course content has been designed, and a “project-based + flipped classroom” hybrid teaching mode, a multi-level practical teaching system, and a school-enterprise collaborative education mechanism have been innovatively implemented. Through the teaching reform, the students' course assessment scores and the rate of achieving the standards for experimental operation skills have significantly improved, and the employment quality of graduates and their alignment with the industry have also been significantly enhanced. Research shows that teaching reforms oriented towards industry demands can effectively improve the quality of course teaching, and can cultivate professional talents with solid theoretical foundation and practical innovation ability in the new energy field. The experience can be used as a reference for similar course reforms in local applied universities.

## 1. Introduction

The global energy landscape is undergoing profound transformation. Driven by China’s “Dual Carbon” strategy, the new energy sector has emerged as a pillar industry in the national economy. The “14th Five-Year Plan for Energy Sector Technological Innovation” clearly states that key technologies such as electrochemical energy storage and hydrogen fuel cells need to be broken through. This places higher demands on the training of new energy-related professionals at universities. As a core course bridging energy conversion and storage, the teaching methodology of Principles of Electrochemistry directly shapes students' engineering competencies. At present, most universities still adhere to the traditional teaching model, which leads to problems such as a disconnect between theory and industrial demands, and insufficient integration of cutting-edge technologies. These issues make it difficult to meet the urgent demand of the new energy industry for skilled professionals with comprehensive capabilities[1, 2].

Shandong Institute of Petroleum and Chemical Technology is a construction unit of an applied-type undergraduate university. The New Energy Science and Engineering major of this university is based on the background of the petroleum and chemical industry. Since its enrollment in 2021, it has always focused on specialized directions such as geothermal energy and hydrogen energy. The curriculum adopts a three-in-one framework integrating "fundamental theories, professional skills, and engineering practice" with Principles of Electrochemistry serving as the cornerstone course. This course plays a pivotal role in developing students' core competencies in electrode process analysis and energy device design. Given the rapid evolution of the new energy sector, there is an urgent need to deepen the integration of curriculum content with industry demands, teaching methodologies with cognitive principles, and practical training with practical engineering applications through pedagogical reforms[3]. This research explores systematic reform pathways for Principles of Electrochemistry based on the university's teaching practices, aiming to provide a replicable model for similar programs in regional energy industries.

## 2. Analysis of the teaching status of Principles of Electrochemistry

### 2.1. Curriculum positioning and teaching objective adaptation

Principles of Electrochemistry is a compulsory major course for sophomore students (32 class hours of theory + 16 class hours of experiments), connecting the prerequisite courses such as Physical Chemistry and Fundamentals of Materials Science with subsequent courses like Energy Storage Materials and Devices, and Hydrogen Technology. The comparison between teaching objectives and enterprise demands shows that (1) the matching degree between mastering the basic theories and calculation methods of electrochemistry and having the ability to analyze battery performance parameters is relatively high; (2) the matching degree between understanding the influencing factors of electrode process kinetics and being able to optimize electrochemical reaction processes is also relatively high; (3) the matching degree between being familiar with typical electrochemical testing techniques and mastering the experimental skills for characterizing battery performance is the highest; (4) the matching degree between understanding the composition principle of electrochemical devices and having the foundation for integrating design of energy storage systems is medium; (5) the matching degree between cultivating scientific research thinking methods and having the ability to propose innovative technical proposals is relatively low.

### 2.2. Problems of traditional teaching mode

There are three core issues in the teaching of electrochemical principles: First, the disconnection between theory and practice. The traditional "definition - formula - example" indoctrination teaching method, such as only deriving the Nernst equation for concentration polarization without combining it with the analysis of concentration changes during lithium battery charging and discharging, leads to students being able to complete exercises but unable to explain the mechanism of battery capacity decline, and being at a loss when facing engineering problems in enterprises. Second, the teaching method is monotonous. The courseware mainly lists text and lacks dynamic interaction. 80% of the experiments are verification-based, and students have no opportunity for independent design. For example, in the hydrogen-oxygen fuel cell experiment, most students cannot analyze the impact of temperature on power, and the cultivation of high-order thinking is insufficient. Third, students' interest is insufficient. The active response rate in the classroom is less than 30%. 73% of the interviewed students hope to increase engineering cases, reflecting a significant gap between the traditional model and cognitive needs.

### 2.3. New requirements for teaching content in industry development

The trend of interdisciplinary integration is reshaping the knowledge boundaries of electrochemistry teaching. Traditional electrochemistry teaching focuses on chemical thermodynamics and kinetics analysis, while modern new energy industries place greater emphasis on interdisciplinary cross-application. The advancement of materials science has driven the design of microstructures for electrode materials. Mechanical engineering principles support the optimization of battery pack structures. Artificial intelligence technology empowers battery performance prediction and life assessment. Shandong Institute of Petroleum and Chemical Technology needs to pay special attention to this interdisciplinary characteristic in curriculum reform. By introducing teaching contents such as material characterization techniques and device simulation software, it aims to cultivate students' systems engineering thinking. For example, when explaining the thermal management of lithium-ion batteries, it is necessary to combine heat transfer theory to analyze the impact of temperature field distribution on battery performance. This multi-dimensional analytical ability is precisely the core assessment point for new energy enterprises when recruiting.

## 3. Theoretical framework of electrochemical teaching reform

### 3.1. Teaching concept of industry-education integration

The educational philosophy of “learning through application and integrating theory with practice” emphasizes transforming practical industrial demands into pedagogical drivers, guiding knowledge construction through authentic engineering challenges. Rooted in John Dewey's pragmatist educational principle that “education is the continuous transformation of experience,” this approach advocates breaking down the isolation of traditional classrooms and establishing dynamic connections between teaching processes and practical production. In developing its New Energy Science and Engineering major, Shandong Institute of Petroleum and Chemical Technology has converted corporate technical challenges into teaching projects, enabling students to deepen theoretical understanding while solving practical problems. For instance, when explaining the phenomenon of electrode polarization, we introduced a case of battery performance degradation provided by a local new energy enterprise. This allowed students to explore the polarization mechanism through data analysis. This kind of learning activity based on real scenarios significantly enhanced the ability of knowledge transfer.

### 3.2. Curriculum goal reconstruction based on OBE concept

The Outcomes-Based Education (OBE) philosophy requires curriculum design to directly align with professional training objectives. Shandong Institute of Petroleum and Chemical Technology's Electrochemistry Principles course has established a three-dimensional framework integrating knowledge, skills, and competencies. The knowledge dimension focuses on systematic mastery of core electrochemical concepts and theoretical systems, while the skills dimension emphasizes progressive development of experimental operations, data analysis, and engineering application capabilities. The competencies dimension cultivates scientific inquiry spirit and innovative thinking through gradual cultivation. This kind of goal setting breaks the traditional situation where knowledge transmission and ability cultivation are disconnected in teaching, and forms a mutually reinforcing educational closed loop.

The achievement evaluation adopts a dual-track mechanism combining “process tracking + outcome verification”. Process evaluation dynamically monitors learning progress through multi-source data including classroom performance, lab logs, and project reports. Final assessment utilizes real-world enterprise projects as evaluation vehicles, such as requiring students to design performance optimization plans for a specific lithium-ion battery model. This evaluation approach ensures students' learning outcomes directly align with industry standards.

### 3.3. Modular curriculum system

The curriculum is structured into three core modules: Fundamental Theory, Applied Practice, and Innovative Research, with a 3:4:3 credit hour allocation that forms a logical progression of “theoretical foundation → practical verification → cutting-edge exploration”. The Fundamental Theory module covers electrolyte solution theory, electrode interface structure, Nernst equation, Tafel equation, and transport processes (16 credit hours: 12 lectures + 4 lab sessions), utilizing a blended teaching approach combining online preparation, classroom instruction, and collaborative discussions to bridge physical chemistry and materials science fundamentals. The Applied Practice module includes lithium-ion battery materials, hydrogen fuel cell mechanisms, electrochemical testing techniques (CV/EIS/LSV), and battery evaluation standards (20 credit hours: 8 lectures + 12 lab sessions), employing flipped classroom methods with hands-on experiments and virtual simulations to connect energy storage materials, devices, and hydrogen energy technologies. The Innovative Research module explores solid-state battery interfaces, nanomaterials electrocatalysis applications, intelligent algorithm prediction, and next-gen energy storage innovations (14 credit hours: 6 expert lectures + 8 project-based assignments), integrating cutting-edge renewable energy technologies and entrepreneurial practice through expert seminars, literature review, and innovation projects.

## 4. Teaching Reform Practice Path of Shandong Institute of Petroleum and Chemical Technology

### 4.1. “Project-based + flipped classroom” hybrid teaching mode

The restructuring of teaching processes begins with redefining learning timelines and spaces. During the pre-class phase, students utilize the super star learning APP to self-study foundational knowledge through micro-lectures and virtual simulations. The system automatically tracks study duration and online test results, enabling teachers to dynamically adjust classroom priorities based on student performance data. In the electrode process dynamics chapter, students must first watch the “Tafel Curve Measurement” virtual experiment. Through interactive operations, they understand how parameters like scanning speed and temperature affect test outcomes. The platform-generated preview reports provide data-driven support for in-class discussions. This proactive learning approach shifts classroom time from knowledge transmission to skill development, increasing instructional efficiency by over 40% per class hour.

The classroom implemented a “project-led, problem-driven” seminar-style teaching approach. Take the “Optimization of Lithium-ion Battery Low Temperature Performance” project as an example. A class of 30 students was divided into 5 interdisciplinary groups, and each group was assigned different research tasks: the materials group focused on the modification of electrode materials, the electrochemistry group was responsible for the design of the performance testing plan, and the data group used the Origin software to perform curve fitting and mechanism analysis. Teachers acted as facilitators, guiding discussions through key questions like "Why does battery capacity decrease by 30% at low temperatures?" and "How to determine electrode reaction reversibility from CV curves?" This approach deepened academic engagement. A group's proposal to "improve lithium-ion diffusion kinetics with nano-porous carbon coatings" was developed into a complete technical report under teacher guidance, which was selected for the university-level Innovation and Entrepreneurship Training Program. Real-time classroom feedback systems revealed that this teaching model increased student participation from 58% in traditional classes to 92%.

The post-class practical expansion establishes an "integration of virtual and physical" learning extension system. On the physical level, students can book projects like "Effect of Different Electrolyte Concentrations on Supercapacitor Performance" through professional laboratory open-access programs. On the virtual level, the "COMSOL Multiphysics" simulation software is used to model how electrode structure parameters influence electrochemical reaction rates. This extended learning approach breaks through time and space constraints, with digital teaching platforms playing a pivotal supporting role throughout the process.

### 4.2. Multi-level practical teaching system

Semi-industrial Training Platform: Collaborating with local new energy enterprises to establish an "Electrochemical Process Training Center", the facility incorporates semi-industrial equipment including decommissioned lithium-ion battery recycling production lines and 5kW fuel cell testing systems. In the "Water Electrolysis for Hydrogen Production" module, students complete end-to-end operations from electrolyte preparation and electrolyzer assembly to hydrogen production rate measurement, gaining insights into how process parameters like current density and temperature affect energy conversion efficiency. Safety training employs VR technology to simulate emergency scenarios such as electrolyte leaks and hydrogen explosions, reinforcing safety awareness through immersive experiences. The training pass rate has increased from 72% before the reform to 95%.

Research and Innovation Platform: The "Undergraduate Lab Entry" program has been implemented, where faculty research projects are broken down into student-friendly sub-topics. During the 2024-2025 academic year, 10 students participated in multiple research initiatives, filed 4 invention patents, and published 2 papers, demonstrating remarkable progress in cultivating scientific innovation capabilities. A discipline-specific competition training system has been established, with dedicated mentorship teams for events like the "Challenge Cup" and "Internet Plus" competitions, systematically developing competencies in literature search, experimental design, and presentation skills.

### 4.3. School-enterprise collaborative education mechanism

To advance industry-academia collaboration, we have established a two-way mobility mechanism between university faculty and corporate technical experts. Faculty members transform R&D cases into teaching materials through industry practice, while senior engineers serve as industrial mentors for curriculum design and graduation project guidance. Our "workshop classroom" integrates real production line scenarios, where theoretical applications are demonstrated through practical operations like electrode coating processes and battery performance testing. Industrial mentors frequently use production accident cases as case studies to guide students in developing an engineering mindset of "problem diagnosis-principle analysis-solution optimization". The practical training adopts a progressive model of "project participation-on-the-job internship-project breakthrough", starting with assisting corporate data analysis before progressing to R&D experiments and process optimization. Graduation projects are predominantly based on enterprise technical requirements, jointly guided by university and corporate mentors. A dynamic feedback mechanism ensures continuous adjustments to curriculum content and practical designs through corporate evaluations of graduates' job adaptability, fostering an ecosystem where education, practice, and employment mutually reinforce each other.

## 5. Effectiveness and reflection of teaching reform implementation

### 5.1. Analysis of teaching quality evaluation results

Following the implementation of educational reforms, Shandong University of Petrochemical Technology's Electrochemistry Principles course has demonstrated comprehensive improvements in teaching quality. Assessment data reveals that students' average scores increased by 12.3 points post-reform, with the percentage of students achieving excellent grades (above 90 points) rising from 15.8% to 32.5%. The failure rate decreased significantly from 8.7% to 2.1%, while the score distribution followed a normal distribution pattern, indicating substantial enhancement in overall teaching effectiveness. In experimental instruction, the operational skill compliance rate rose from 76.4% to 94.2%, with the “independent experimental design” metric showing the most notable improvement. This progression highlights the positive impact of project-based learning on cultivating practical competencies.

### 5.2. Effect of cultivating students' innovation ability

Since the implementation of the reform, students have published 2 papers as first authors (with an average impact factor of 3.8), and have applied for 4 invention patents (with 1 being approved). The proportion of graduates entering the R&D positions of leading new energy enterprises has increased from 12% to 29%. Employers have reported that the graduates' ability to propose innovative solutions is significantly better than that of the employees who joined at the same time.

### 5.3. Problems and optimization direction in the reform process

First, the allocation of teaching resources remains uneven. Current electrochemical workstations can only accommodate 50% of students conducting advanced experiments simultaneously. Plans include adding 8 high-precision devices by 2026 and developing virtual experiment systems. Secondly, corporate engagement is insufficient, with plans to establish an “enterprise mentor residency program” where two engineers will be assigned full-time annually for curriculum development. Thirdly, interdisciplinary faculty reserves are inadequate, requiring implementation of a “dual-qualified teacher training program” that dispatches three faculty members for corporate internships each year while recruiting two specialized instructors. Finally, the process-oriented evaluation system needs improvement, necessitating the creation of a “student innovation capability radar chart” assessment tool. Outdated teaching content requires establishing an “industrial technology intelligence tracking mechanism” to ensure content updates keep pace with technological advancements within six months.

## 6. Conclusions

The teaching reform of electrochemical principles in the New Energy Science and Engineering major of Shandong Institute of Petroleum and Chemical Technology has established a three-in-one framework of "industry-academia integration, OBE orientation, and module reconfiguration", forming a distinctive teaching model. The core experience is as follows: through the joint laboratory of the school and enterprises to realize the realization of teaching scenarios, the project-based flipped classroom breaks the traditional time and space limitations, and the multi-level practical system connects the chain of ability cultivation. The reform effectively solves the problem of disconnection between theory and practice, and significantly improves students' engineering application and innovative thinking, providing a replicable sample for application-oriented universities. In the future, it will deepen intelligence and internationalization, continuously resonate with the industry at the same frequency, and cultivate high-quality application-oriented innovative talents needed for energy transformation.

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