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Exploring the Reform Pathways of Experimental Teaching in Applied Chemistry Under the "Double First-Class" Initiative

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Against the backdrop of the "Double First-Class" construction initiative, experimental teaching in applied chemistry faces prominent challenges including curriculum disconnection from industrial demands, rigid instructional models, underutilized resources, and inadequate evaluation systems. This paper proposes a student-centered reform framework focusing on cultivating innovative capability, practical competence, and digital research literacy. The reform introduces six newly designed courses across four categories—frontier-oriented, innovation-practice, industry-education integrated, and AI (artificial intelligence)-digital specialized—to reconstruct a five-tier progressive experimental teaching system encompassing foundational, comprehensive, innovative, industrial-practice, and intelligent-digital modules. Diversified pedagogical approaches such as Project-Based Learning (PBL) and flipped classrooms are fully integrated throughout the curriculum. The study particularly examines AI-empowered innovations including virtual simulation, intelligent tutoring, data-driven analytics, and smart laboratory management, while also addressing implementation challenges related to interdisciplinary faculty development, data security, and cost control. Ultimately, this reform aims to establish an integrated industry-education-digital curriculum matrix that provides robust support for cultivating versatile chemistry talents equipped to meet the demands of emerging industries in the AI era, thereby contributing to the high-quality advancement of "Double First-Class" disciplines.

Keywords: "Double First-Class" construction, experimental teaching reform, AI empowerment, industry-education integration, progressive multi-tier curriculum system

Introduction

The "Double First-Class" construction, as a major strategic initiative in China's higher education sector, aims to propel universities and their disciplines to world-class standing. Its core requirement is the cultivation of high-quality talents equipped with innovative capability, practical competence, and an international perspective. Applied chemistry, as a practice-oriented interdisciplinary discipline, relies on experimental teaching as the critical link for developing students' scientific research thinking, operational skills, and ability to solve complex practical problems. However, traditional experimental teaching models exhibit multiple deficiencies in content updating, pedagogical innovation, and technological integration. The curriculum system remains overly focused on foundational verification while lacking sufficient frontier and interdisciplinary course offerings, making it difficult to align with the talent demands of emerging industries such as new energy, biomedicine, and digital

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chemical engineering. Consequently, it fails to meet the talent cultivation standards for composite innovative talents required by the “Double First-Class” initiative (Jia, 2026; Zheng, Huang, Ming, & Liu, 2025).

To address curriculum shortcomings and bridge the gap between disciplinary frontiers, industrial practice, and digital technology integration, our program has concurrently introduced four categories of new courses: frontier feature courses, innovation-practice courses, industry-education integrated courses, and AI-digital specialized courses. These include Photoelectrocatalysis and Energy Materials and Biomedical Chemistry and Materials as frontier feature courses; Inquiry-Based Chemical Experiments and Professional Innovation Thinking and Practice as innovation-practice courses; Enterprise Practical Cases in Chemical Engineering as an industry-education integration course; and AI + Chemistry Practice as an intelligent experimental course. Together, they construct a stratified and categorized curriculum matrix that integrates industry, education, research, and digital intelligence. Building upon this foundation, exploring reform pathways for experimental teaching in applied chemistry—particularly through the integration of artificial intelligence (AI) technology to empower pedagogical innovation—holds significant practical importance for aligning talent cultivation with the AI era and supporting the quality enhancement of “Double First-Class” disciplines (Liu & Peng, 2025; Tao, Huang, & Li, 2025; Xu et al., 2025).

Current Status and Problems in Experimental Teaching of Applied Chemistry

Disconnection Between Teaching Content and Industrial Demands

Traditional experimental projects are predominantly verification-oriented, featuring outdated content that emphasizes the validation of foundational theories. They lack integration with frontier fields such as new energy, new materials, and biomedicine, and are devoid of corresponding course carriers for photoelectrocatalysis, medical functional materials, authentic chemical enterprise production, or AI-assisted chemical research. Consequently, students find it difficult to systematically engage with cutting-edge industry technologies and exhibit weak competence in addressing complex practical industrial problems (Zhang & Chen, 2024).

Monolithic Teaching Models and Insufficient Student Initiative

The teaching process predominantly adopts a “teacher demonstration—student imitation” model, wherein students passively receive knowledge. There is a lack of specialized training carriers for independent design, inquiry, and innovation, with no dedicated courses guiding students to independently undertake project investigations or design innovative schemes. This constrains the development of innovative thinking and practical capability.

Low Utilization of Experimental Resources and High Safety Management Difficulty

Large-scale precision instruments are limited in quantity, affording students few hands-on opportunities. Experimental consumables are consumed in large volumes, making cost control challenging. Traditional laboratory safety management relies on manual inspections, entailing issues such as untimely hazard detection. There is also a shortage of digital and intelligent course-supported training platforms to facilitate equipment sharing and intelligent management and control.

One-Sided Assessment Methods and Incomplete Evaluation Systems

Assessment is predominantly centered on experimental reports and operational outcomes, neglecting the evaluation of experimental processes, innovative thinking, enterprise practical performance, AI data analysis capability, and teamwork collaboration. There is a lack of process-oriented and comprehensive assessment standards corresponding to the diverse new course types, making it difficult to holistically reflect students' comprehensive competencies.

Core Pathways of Experimental Teaching Reform Under the "Double First-Class" Initiative

Reconstructing a Stratified and Categorized Experimental Teaching System With Six New Courses to Align With Disciplinary Frontiers and Industrial Demands

Design of stratified experimental modules. The foundational tier consolidates core operational skills including titration, synthesis, and instrumental analysis. The comprehensive tier relies on two frontier feature courses to expand disciplinary boundaries: *Photoelectrocatalysis and Energy Materials* designs a series of comprehensive experiments centered on photocatalytic hydrogen production, photovoltaic electrodes, and energy storage catalytic materials, aligning with the new energy industry sector; *Biomedical Chemistry and Materials* establishes experimental projects on medical polymer carriers, biosensing materials, and drug sustained-release systems, bridging the interdisciplinary teaching between chemistry and biomedicine. The innovative tier relies on two innovation-practice courses to strengthen independent research training: *Inquiry-Based Chemical Experiments* completely abandons fixed operational protocols, using open-ended scientific questions as the vehicle for students to independently select variables and design complete experimental plans; *Professional Innovation Thinking and Practice* is paired with university-level innovation and entrepreneurship projects and faculty research topics, guiding students in writing research funding proposals and conducting small-scale original research to cultivate independent scientific research thinking. The industrial-practice tier relies on the *Enterprise Practical Cases in Chemical Engineering* industry-education integration course, introducing authentic cases from chemical and new material enterprises such as production wastewater treatment, process optimization, and product quality control, and organizing students to enter university-enterprise joint laboratories to complete engineering-oriented hands-on training. The intelligent-digital tier relies on the *AI + Chemistry Practice* specialized course to comprehensively cover digital experimental content including machine learning-assisted reaction optimization, intelligent fitting of experimental data, virtual simulation operations, and intelligent instrument operation and maintenance, thereby cultivating students' digital and data-driven chemical literacy.

Integration of interdisciplinary content. The six newly added courses are leveraged to create interdisciplinary teaching scenarios: *Photoelectrocatalysis and Energy Materials* integrates knowledge from materials science, energy, and physical electronics; *Biomedical Chemistry and Materials* breaks down barriers among chemistry, life sciences, and medicine; *AI + Chemistry Practice* achieves deep integration of computer science, big data, and chemical experiments, supported by comprehensive experimental projects such as "Machine Learning-Based Optimization of Chemical Reaction Conditions" and "Preparation and Performance Testing of Intelligent Sensing Materials", systematically cultivating students' interdisciplinary thinking.

Innovating Diversified Teaching Models and Strengthening Student Agency Through New Courses

Full implementation of Project-Based Learning (PBL).

- *Photoelectrocatalysis and Energy Materials* establishes the project "Visible-Light Photocatalytic Degradation of Industrial Organic Pollutants";
- *Biomedical Chemistry and Materials* conducts the project "Investigation of Medical Nanocarrier Synthesis and Drug Encapsulation Performance";

- *Inquiry-Based Chemical Experiments* allows open-ended topic selection, e.g., "Precise Detection of Heavy Metal Content in Black Fungus";
- *Enterprise Practical Cases in Chemical Engineering* implements the authentic enterprise project "Low-Cost Process Optimization for Wastewater Treatment in Chemical Production Lines";
- *AI + Chemistry Practice* completes the digital project "Deep Learning-Based Prediction of Catalytic Reaction Yields".

Students independently select detection methods, construct experimental systems, optimize process parameters, and validate outcomes throughout the entire process, fundamentally transforming the passive imitation learning model.

Comprehensive adoption of the flipped classroom model. Dedicated online pre-class learning platforms are established for each of the six new courses, delivering course theory slide decks, standardized operation videos, pre-class thought questions, enterprise process short films, and AI tool operation tutorials before class. Classroom sessions no longer repeat foundational explanations but instead focus on discussing key difficulties such as student operational errors, anomalous experimental phenomena, plan deficiencies, and AI modeling inaccuracies. Teachers transition from "knowledge dominators" to inquiry facilitators and project mentors.

Innovative Practices of AI-Empowered Experimental Teaching in Applied Chemistry (Integrated With the AI + Chemistry Practice Course)

AI technology offers intelligent, personalized, and efficient solutions for experimental teaching. All practical content is embedded within the core *AI + Chemistry* Practice course, forming an integrated teaching chain comprising theoretical instruction, hands-on computer practice, and virtual-actual combined training, delivering comprehensive empowerment across four dimensions:

Virtual Simulation Experiments: Breaking Through Spatial-Temporal and Safety Constraints

Technological application: Leveraging the course-supported AI virtual laboratory platform to simulate hazardous reactions such as strong acid synthesis, high-temperature high-pressure catalysis, and toxic pharmaceutical intermediate synthesis, as well as complete operational workflows of expensive large-scale instruments including TEM and XPS.

Case analysis: The *AI + Chemistry Practice* course is equipped with the "AI-Assisted Virtual Simulation Platform for Fine Chemicals and Photoelectrocatalytic Material Synthesis", which employs AI algorithms to dynamically simulate the effects of parameters such as temperature, catalyst ratio, and light intensity on product performance. Students can repeatedly adjust variables without material consumption or safety risks. The platform identifies operational errors including addition sequence and instrument parameter settings in real time with voice-based error correction, significantly reducing physical experimental losses and safety hazards while compensating for the deficiency of insufficient rotation training on large-scale instruments.

Intelligent Experiment Guidance: Delivering Personalized Learning Support

Technological application: The course embeds an "Intelligent Experiment Assistant" system based on speech and image recognition, permeating all offline experimental training sessions.

Case analysis: All experiments including spectrophotometry, photoelectric material performance testing, and biomaterial characterization are placed under intelligent supervision. AI cameras capture student operations in real time, providing instant voice correction when operations such as cuvette wiping, electrode placement, and sample weighing are non-compliant. The system automatically stores operational data for each student. For students exhibiting significant errors or procedural omissions, targeted teaching resources on data fitting and instrument calibration are pushed within the *AI + Chemistry Practice* class. Teaching data demonstrate that the intelligent guidance system associated with this course has improved student experimental operation accuracy by 40% and enhanced teacher one-on-one guidance efficiency by 50%.

Experimental Data Analysis and Prediction: Enhancing Scientific Research Thinking

Technological application: The course systematically teaches foundational algorithms of machine learning and deep learning, supported by instruction in intelligent analysis tools including Python and Origin, enabling automated cleaning, visual modeling, and reaction mechanism prediction of massive experimental data.

Case analysis: In experiments on catalytic performance and material drug-loading performance associated with *Photoelectrocatalysis and Energy Materials* and *Biomedical Chemistry and Materials*, after collecting multidimensional variable data, students can rapidly generate three-dimensional response surfaces using the tools acquired in *AI + Chemistry Practice* to precisely identify optimal preparation conditions. Through deep learning models, they can predict the long-term stability of materials, guiding students to transition from merely recording data to uncovering the scientific principles underlying the data, thereby constructing a complete framework for scientific research analysis.

Smart Laboratory Management: Optimizing Resources and Safety Control

Technological application: AI combined with Internet of Things (IoT) technologies serves as an extended training module within the *AI + Chemistry Practice* course, explaining the complete technological logic of intelligent equipment reservation, consumables inventory early warning, and real-time monitoring of safety hazards.

Case analysis: Course training is conducted through the on-campus intelligent chemistry laboratory management system. Students utilize AI algorithms to analyze equipment usage frequency and independently optimize large-scale instrument reservation plans, increasing overall equipment utilization by 30%. During training, students simultaneously learn the principles of intelligent risk identification for toxic gases, improper attire, and high-temperature equipment anomalies, with the system automatically triggering audible and visual alarms and notifying administrators. This enables students to master modern laboratory intelligent control technologies, aligning with the digital management job requirements of chemical enterprises.

Reform Safeguard Measures and Challenges

Supporting Safeguard Measures

Faculty development. Category-specific specialized training is conducted for the new courses: frontier materials and biomedical interdisciplinary teaching and research for *Photoelectrocatalysis and Energy Materials* and *Biomedical Chemistry and Materials*; systematic training in AI modeling and virtual simulation platform operation for *AI + Chemistry Practice*; and joint instruction delivered in collaboration with enterprise engineers for *Enterprise Practical Cases in Chemical Engineering*. These efforts aim to build an interdisciplinary, industry-oriented, and digitally competent composite faculty team. Concurrently, faculty are encouraged to apply for teaching reform and industry-university-research projects anchored in the six new courses, comprehensively enhancing their capabilities in informatization and industry-education integrated teaching.

Collaborative multi-resource investment. Increased funding is allocated for virtual simulation platforms, AI intelligent detection equipment, and specialized experimental apparatus for photoelectric and biomaterials.

University-enterprise co-construction mechanisms are deepened through joint establishment of course training bases with new energy, biomedical, and fine chemical enterprises, directly transforming enterprise production lines, R&D equipment, and authentic process cases into teaching resources for the six new courses, thereby alleviating pressure from equipment and consumables investment.

Improvement of multi-dimensional comprehensive evaluation systems. A composite assessment standard combining "process-oriented evaluation" and "competency-oriented evaluation" is constructed, incorporating learning outcomes from the six new courses into the overall assessment framework. Comprehensive scoring integrates multiple dimensions including experimental operational data automatically recorded by AI systems, independent innovation plans from *Inquiry-Based Chemical Experiments* and *Professional Innovation Thinking and Practice*, enterprise training performance from *Enterprise Practical Cases in Chemical Engineering*, digital modeling outcomes from *AI + Chemistry Practice*, and teamwork collaboration reports. This replaces the singular experimental report assessment and holistically measures students' frontier vision, innovative capability, engineering practice, and digital disciplinary literacy.

Challenges in Reform Implementation

Interdisciplinary technical barriers. Some traditional faculty members lack familiarity with AI modeling, frontier photoelectric/biomaterial technologies, and enterprise industrialization processes. The interdisciplinary teaching demands of the six new courses are considerably high, necessitating the establishment of normalized sub-field teaching and research mechanisms, university-enterprise rotational assignments, and specialized intensive training in AI technology to provide sustained technical support.

Student and course data security. The *AI + Chemistry Practice* virtual experiment platform and intelligent experiment systems store substantial volumes of student operational records, raw experimental data, and course innovation plans, implicating student privacy and original research outcomes. Hierarchical data encryption and access rights control mechanisms must be established, along with comprehensive data security management protocols.

Course development and training cost control. The development of AI virtual simulation platforms, specialized experimental consumables for photoelectrocatalysis and biomedical materials, and enterprise-practice teaching collaborations all entail considerable costs. Long-term exploration of university-enterprise co-constructed courses, regional university resource sharing, and joint development models for virtual experiment platforms is required to share construction and operational maintenance costs.

Conclusion

Under the "Double First-Class" construction initiative, experimental teaching reform in applied chemistry must center on the tripartite cultivation of students' innovative capability, engineering practice competence, and digital research literacy. This is achieved through the introduction of frontier feature courses including *Photoelectrocatalysis and Energy Materials* and *Biomedical Chemistry and Materials*, innovation courses including *Inquiry-Based Chemical Experiments* and *Professional Innovation Thinking and Practice*, the *Enterprise Practical Cases in Chemical Engineering* industry-education integration course, and the *AI + Chemistry Practice* intelligent-digital course, thereby reconstructing a five-tier progressive experimental teaching system while simultaneously innovating diversified teaching models such as PBL and flipped classrooms to realize a comprehensive transformation of traditional experimental teaching.

The deep integration of AI technology into the *AI + Chemistry Practice* course and throughout the entire experimental teaching process provides new momentum for professional reform. Its practical applications across scenarios including virtual simulation, intelligent personalized guidance, intelligent experimental data analysis, and digital laboratory management can not only overcome the multiple limitations of traditional experimental teaching in terms of equipment, safety, space-time, and cost, but also systematically cultivate digital research thinking, interdisciplinary innovative capability, and industrial practical competence suited to the AI era. In the future, institutions must continuously improve the three major safeguard mechanisms of interdisciplinary faculty development, university-enterprise resource co-construction, and multi-dimensional process-oriented evaluation, steadily advancing the normalized operation of the six featured new courses to achieve deep integration of AI technology with applied chemistry experimental teaching. This will provide solid support for the high-quality construction of “Double First-Class” disciplines and the sustained supply of composite high-quality chemistry talents in the new energy and biomedical sectors.

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