World Journal of Educational Studies
Print ISSN: 2959-9989
Online ISSN: 2959-9997
DOI: https://doi.org/10.61784/wjes3177

THE SMART EXPERIMENTAL REFORM OF PRINCIPLES OF CHEMICAL ENGINEERING LABORATORY COURSE FOR CHEMICAL ENGINEERING MAJORS UNDER THE EMERGING ENGINEERING EDUCATION

BinBin Xin[1], HuiBo Qin[1], Chen Pan[2], Jun Yang[1], SuHua Wang[3], Long Yu[3*], Lei Wang[1*]
[1]School of Chemical Engineering, Guangdong University of Petrochemical Technology, Maoming 525000, Guangdong, China.
[2]Architecture and Civil Engineering Institute, Guangdong University of Petrochemical Technology, Maoming 525000, Guangdong, China.
[3]School of Environmental Science and Engineering, Guangdong University of Petrochemical Technology, Maoming 525000, Guangdong, China.
[*]These authors contributed equally to this work.
[*]Corresponding Author: Long Yu, Lei Wang

Abstract: Driven by both the Emerging Engineering Education initiative and the digital transformation of education, experimental teaching in chemical engineering-related majors faces an urgent need to transition from "verification-oriented operations" to "smart education-oriented cultivation". Taking the "Principles of Chemical Engineering Experiment" course at Guangdong University of Petrochemical Technology as an example, this paper systematically elaborates on the existing foundation, construction goals, main contents, and expected outcomes of the smart reform of this course. The study proposes that by constructing a knowledge graph, recording MOOC experiment videos, improving the virtual simulation platform, establishing a blended online and offline teaching system, and empowering with AI technology, the traditional experimental teaching limitations of "teacher-centered, fixed procedures, and single evaluation" can be effectively broken. The practical path shows that the smart experimental reform not only enhances students' independent design and innovation abilities but also strengthens the cultivation of engineering ethics and the awareness of industry-university-research integration, providing a replicable reference paradigm for the high-quality development of similar experimental courses in chemical engineering.

Keywords: Emerging engineering education; Principles of chemical engineering experiment; Smart course; Blended online and offline teaching; Knowledge graph; Virtual simulation

1 INTRODUCTION

With the advancement of the national Emerging Engineering Education (New Engineering) construction and the digital transformation of education, experimental teaching in chemical engineering faces a significant transition from traditional "verification-oriented operations" to "smart education-oriented cultivation" [1-2]. Emerging Engineering Education emphasizes industry-demand orientation and the cultivation of compound talents with engineering practice ability, interdisciplinary thinking, and innovative spirit, which places higher demands on foundational courses, especially "Principles of Chemical Engineering" and its experimental teaching [3-4]. As a key link connecting theory and engineering practice, the "Principles of Chemical Engineering" and its supporting experimental teaching play an important role in cultivating students' practical ability, innovative thinking, and awareness of engineering ethics [5].

However, for a long time, the following problems have been prevalent in the experimental teaching of Principles of Chemical Engineering: the "verification-oriented" teaching model dominated by teacher demonstration limits students' exploration space; experimental evaluation overly relies on experiment report forms, neglecting the assessment of process abilities and engineering thinking; insufficient application of information and intelligent teaching tools makes it difficult to achieve personalized and precise teaching [6-7]. Moreover, the traditional experimental teaching model is often confined to a "teacher-centered" approach with fixed procedures and a single evaluation, which not only limits students' self-learning ability but also fails to fully leverage the potential of emerging technologies in education [8-9].

Faced with these challenges, how to leverage emerging technologies such as "Internet+", artificial intelligence (AI), and knowledge graphs to promote the smart transformation of the Principles of Chemical Engineering experiment course has become an important direction for current chemical engineering education reform [10-11]. This study takes the "Principles of Chemical Engineering Experiment" course at Guangdong University of Petrochemical Technology as a pilot and systematically explores the path and practical experience of the smart reform of this course [12-13]. By constructing a knowledge graph, recording MOOC experiment videos, improving the virtual simulation platform, establishing a blended online and offline teaching system, and empowering with AI technology, a set of innovative smart experimental reform plans is proposed [14-15].

This paper aims to elaborate, from theory to practice, the multi-dimensional exploration of the smart experimental reform of Principles of Chemical Engineering under the Emerging Engineering Education background, analyze its role in improving students' self-learning ability, engineering design ability, and innovation ability, while strengthening students' awareness of engineering ethics and industry-university-research integration. Through specific case studies, this paper provides replicable practical experience and theoretical reference for the high-quality development of similar experimental courses in chemical engineering, injecting new vitality into the reform of chemical engineering education under the Emerging Engineering Education background.

2 EXISTING FOUNDATION OF THE COURSE

2.1 Basic Course Information

The "Principles of Chemical Engineering Experiment" is divided into two courses (I) and (II), totaling 2 credits and 40 class hours. It is offered to sophomore and junior students from nine majors including Chemical Engineering, Energy Engineering, Applied Chemistry, Environmental Science, Polymer Materials, and Functional Materials, with an experimental teaching task of nearly one thousand students per semester. The experiment types cover verification experiments (e.g., Reynolds demonstration, energy conversion, absorption, extraction), comprehensive experiments (centrifugal pump comprehensive experiment, heat transfer comprehensive experiment), and design experiments (fluid flow resistance design, distillation design). The specific experimental items and class hour distribution have formed a complete system, as shown in Table 1.

Table 1 Distribution of Principles of Chemical Engineering Experiments

Supporting Textbook	Experiment Name	Type	Hours
Principles of Chemical Engineering Experiment (I)	Reynolds Demonstration Experiment	Verification	0
	Energy Conversion Experiment	Verification	2
	Energy Conversion Experiment	Verification	2
	Centrifugal Pump Comprehensive Experiment	Comprehensive	6
	Heat Transfer Comprehensive Experiment	Comprehensive	4
	Constant Pressure Filtration Experiment	Verification	4
Principles of Chemical Engineering Experiment (II)	Distillation Design Experiment	Design	6
	Absorption Experiment	Verification	6
	Extraction Experiment	Verification	4
	Drying Experiment	Verification	4

2.2 Teaching Conditions and Textbook Development

The course relies on the Guangdong Provincial Chemical and Chemical Engineering Basic Experimental Teaching Demonstration Center, with multiple specialized laboratories for fluid mechanics, drying, filtration, heat transfer, distillation, absorption, extraction, etc., equipped with smart chemical engineering experimental devices provided by Laipake (Beijing) Technology Co., Ltd. The self-compiled textbook "Principles of Chemical Engineering Experiment" by the teaching team has been updated to its third edition, supporting the standardized operation of experimental teaching, as shown in Figure 1.

3 CONSTRUCTION GOALS OF THE SMART EXPERIMENTAL REFORM

Addressing the core pain points of traditional experimental teaching---"single method, fixed content, and lack of innovation"---the course team has established the following four reform goals, as shown in Figure 2:

3.1 Knowledge Graph Construction

Based on Information Organization Theory (IOI) and knowledge engineering, organize the core elements of the "Principles of Chemical Engineering Experiment" course, establish a dedicated knowledge graph to achieve knowledge visualization, intelligent retrieval, and learning path recommendation.

3.2 Virtual Simulation Platform Development

Based on human-computer interaction theory and educational information technology, build a fully functional virtual simulation system to digitize and visualize experimental processes, facilitating students' repeated practice and innovative design.

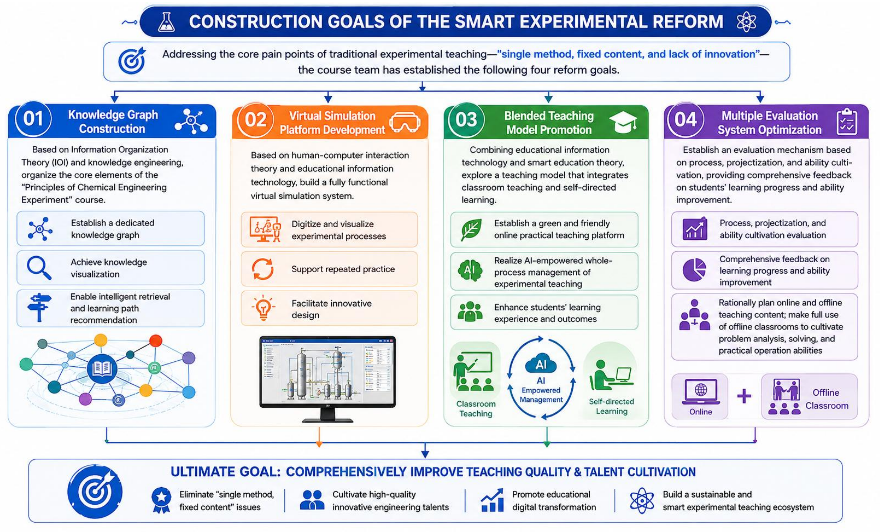
Figure 1 Principles of Chemical Engineering Laboratory

3.3 Blended Teaching Model Promotion

Combining educational information technology and smart education theory, explore a teaching model that integrates classroom teaching and self-directed learning, establish a green and friendly online practical teaching platform, and realize AI-empowered whole-process management of experimental teaching to enhance students' learning experience and outcomes.

3.4 Multiple Evaluation System Optimization

Establish an evaluation mechanism based on process, projectization, and ability cultivation, providing comprehensive feedback on students' learning progress and ability improvement. Rationally plan online and offline teaching content, and make full use of offline classrooms to cultivate students' abilities to analyze problems, solve problems, and practice operation.



CONSTRUCTION GOALS OF THE SMART EXPERIMENTAL REFORM

Addressing the core pain points of traditional experimental teaching—"single method, fixed content, and lack of innovation"—the course team has established the following four reform goals.

01 Knowledge Graph Construction

Based on Information Organization Theory (IOI) and knowledge engineering, organize the core elements of the "Principles of Chemical Engineering Experiment" course.

Establish a dedicated knowledge graph

Achieve knowledge visualization

Enable intelligent retrieval and learning path recommendation

02 Virtual Simulation Platform Development

Based on human-computer interaction theory and educational information technology, build a fully functional virtual simulation system.

Digitize and visualize experimental processes

Support repeated practice

Facilitate innovative design

03 Blended Teaching Model Promotion

Combining educational information technology and smart education theory, explore a teaching model that integrates classroom teaching and self-directed learning.

Establish a green and friendly online practical teaching platform

Realize AI-empowered whole-process management of experimental teaching

Enhance students' learning experience and outcomes

04 Multiple Evaluation System Optimization

Establish an evaluation mechanism based on process, projectization, and ability cultivation, providing comprehensive feedback on students' learning progress and ability improvement.

Process, projectization, and ability cultivation evaluation

Comprehensive feedback on learning progress and ability improvement

Rationally plan online and offline teaching content; make full use of offline classrooms to cultivate problem analysis, solving, and practical operation abilities

ULTIMATE GOAL: COMPREHENSIVELY IMPROVE TEACHING QUALITY & TALENT CULTIVATION

Eliminate "single method, fixed content" issues

Cultivate high-quality innovative engineering talents

Promote educational digital transformation

Build a sustainable and smart experimental teaching ecosystem

Figure 2 Construction Goals of the Smart Experimental Reform

4 MAIN CONTENTS OF THE SMART EXPERIMENTAL REFORM

Building upon the existing theoretical teaching and practice bases, the course team places student ability development at the core and follows a progressive logic from resource digitization and process datafication to evaluation multidimensionalization and teaching model smartification, as shown in Figure 2.

4.1 Construction and Dynamic Updating of a Full-Cycle Experimental Video Resource Library

The laboratory is already equipped with equipment explanation videos provided by Laipake Company, covering device structure, principles, and basic operating procedures. However, these video resources are fragmented, lack interactivity, and do not cover all experimental items. The reform measurements is following:

4.1.1 Systematic completion

For every unit operation experiment (fluid flow, heat transfer, distillation, absorption, etc.), a full-process video is produced covering “equipment familiarization-parameter setting-operating procedure-anomaly handling-data recording”, forming a standardized video library.

4.1.2 Embedded interactive quizzes

At key points in each video, thought-provoking questions pop up (e.g., “Why must distillation start with total reflux before switching to partial reflux?”). Students must answer before continuing, and the system automatically records the correct-answer rate.

4.1.3 Dynamic updating mechanism

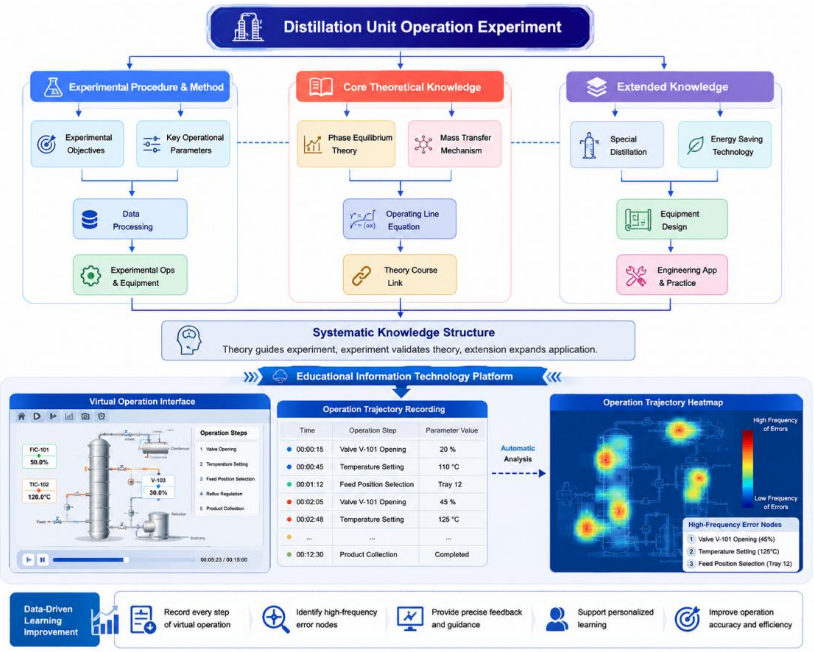
Following the action research method, student feedback and common operational errors are collected every semester. Micro-video modules such as “Common Misconceptions Explained” and “Exemplary Operation Demonstrations” are added accordingly.

4.2 Iteration and Data Integration of the Intelligent Virtual Simulation Platform

The current virtual simulation platform suffers from unintelligent data statistics, an incomplete question bank, and disconnection from the hands-on experiment segment.The reform measurements is following:

4.2.1 Automatic collection of full behavioral data

Based on educational information technology, the platform records every step of a student’s virtual operation (e.g., valve opening, temperature setting, feed position selection) and automatically generates an “operation trajectory heatmap” to identify high-frequency error nodes (As shown in Figure 3).



Theory guides experiment, experiment validates theory, extension expands application.

Time	Operation Step	Parameter Value
● 00:00:15	Valve V-101 Opening	20 %
● 00:00:45	Temperature Setting	110 °C
● 00:01:12	Feed Position Selection	Tray 12
● 00:02:05	Valve V-101 Opening	45 %
● 00:02:48	Temperature Setting	125 °C
● ...	...	...
● 00:12:30	Product Collection	Completed

Figure 3 Knowledge Graph Construction

4.2.2 Closed-loop design between virtual and hands-on practice

Only after completing the virtual simulation and obtaining an “operation certificate” can a student proceed to the offline hands-on experiment. Key data generated in the hands-on session (e.g., actual tray efficiency) can be sent back to the platform for comparative analysis with virtual results, thereby cultivating students’ ability to perform error analysis and model calibration.

4.2.3 Intelligent feedback and question bank expansion

The platform embeds a tiered question bank (from basic questions to comprehensive application problems to design optimization problems). When a student answers incorrectly, relevant theoretical knowledge snippets are automatically pushed. An interface is also provided for instructors to add custom questions, supporting continuous expansion.

4.3 Construction of a Visual Knowledge Graph Based on Knowledge Engineering

Knowledge points across different experimental units are scattered, making it difficult for students to form a systematic understanding of the “theory → experiment → engineering application” chain, which can be built by these reforming:

4.3.1 Core element extraction and association modeling

Based on Information Organization Theory (IOI), for each unit operation experiment (using distillation as an example, shown in Figure 4), three types of nodes are extracted-theoretical knowledge points (e.g., phase equilibrium, tray efficiency, reflux ratio), experimental skill points (e.g., feeding operation, sampling analysis), and engineering application points (e.g., energy-saving optimization, fault diagnosis).

4.3.2 Intelligent learning path recommendation

The knowledge graph is linked to student learning behavior data. If a student spends too much time on a theoretical knowledge node or has a high error rate on related quizzes, the system automatically pushes prerequisite basic knowledge videos and virtual exercises. For advanced learners, extended engineering cases (e.g., dividing-wall column distillation technology) are recommended.

4.3.3 Cross-course linking

The Principles of Chemical Engineering Experiment knowledge graph is semantically linked to the knowledge graphs of theoretical courses such as Chemical Engineering Thermodynamics and Separation Engineering, helping students understand where the experiment sits within the overall disciplinary system.

4.4 Design Reconstructing a Task-Driven Blended Online and Offline Experimental Teaching Model

The division between online and offline content is vague, and pre-class preview is dominated by passive watching, lacking a design-oriented task driver. The process is shown in Figure 4.

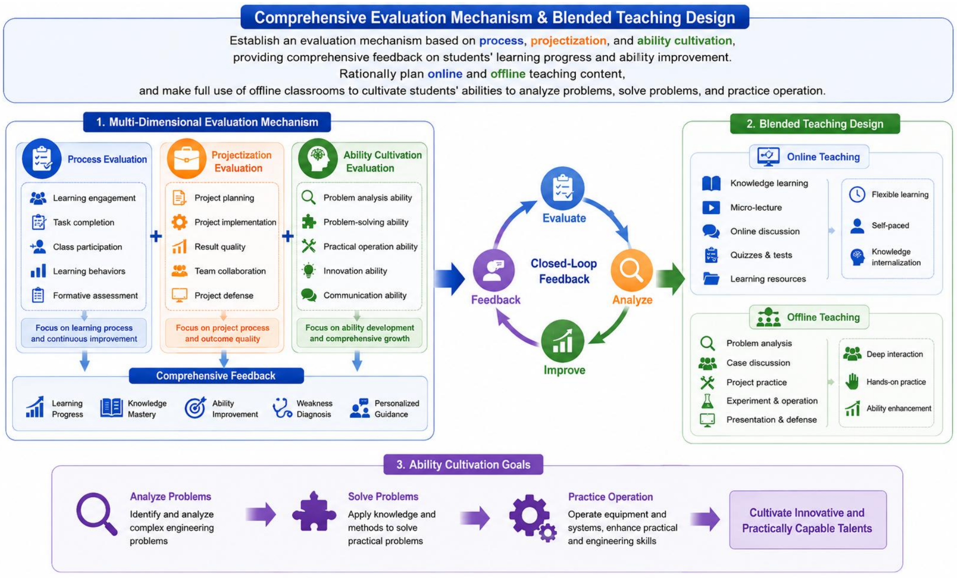


Figure 4 Construction of Blended Online and Offline Experimental Teaching

The specific teaching process is as follows:

4.4.1 Online segment (before class)

Task release: Around engineering themes such as “three transfers (momentum, heat, mass transfer) and energy saving”, instructors release a design-oriented preview task sheet (e.g., “Design the reflux ratio and feed position for a distillation experiment given the feed composition and required product purity”). Self-directed exploration: Students watch targeted experiment videos → perform trial operations on the virtual simulation platform → consult literature (CNKI, ACS, etc.) → complete a preliminary experimental design plan and submit it to the platform. **Peer review in groups:** The system randomly assigns 2–3 other groups’ plans for anonymous peer review. Students raise questions or suggest improvements. The instructor extracts common issues online for classroom discussion.

4.4.2 Offline segment (in class):

Focused problem-based discussion: The instructor spends only five minutes highlighting safety points and special equipment precautions. The remaining time is devoted to “proposal defense” discussions-each group sends a representative to present their design plan, while other groups and the instructor collectively query (e.g., “How do you ensure data repeatability?”). Comparative and design-oriented experiments: Change core equipment parameters (e.g., distillation column insulation conditions, heat exchanger flow pattern). Different groups cross-compare results and analyze the influence mechanisms of the parameters. Students carry out hands-on operations according to their own design plans, record deviations between actual data and expectations, and analyze whether the cause lies in operational issues or model assumptions. They then submit a “deviation attribution report”.

4.5 Construction Multi-Dimensional Tiered Question Bank System and Intelligent Test Assembly

The original question bank is fragmented and has a single question type, making it unable to support differentiated assessment needs in blended teaching. Three types of question banks are systematically built. Each type is labeled with a difficulty level and knowledge point tags.

4.5.1 Experimental design bank

Contains excellent student design plans, instructor demonstration plans, and typical engineering cases (including erroneous cases) for students to consult and learn from critically.

4.5.2 Experimental exercise bank

Organized by unit operation chapters. Each chapter includes basic questions (equipment structure, operation steps), application questions (anomaly analysis), and comprehensive questions (multi-factor optimization design).

4.5.3 Experimental thinking question bank

Used for online preview self-tests and classroom discussions. Most questions are open-ended (e.g., “If flooding occurs in a distillation column, from which aspects would you begin troubleshooting?”). No standard answer is provided, but scoring dimensions are given.

4.5.4 Intelligent test assembly

Based on students’ historical learning data, the platform automatically generates personalized preview tests or review tests, enabling differentiated practice with “one student, one unique question set”.

4.6 A Full-Process, Data-Driven Multiple Evaluation System for Experimental Teaching

Through a weight design of "online preview score + offline operation score" each accounting for 50%, a whole-process, multi-dimensional learning evaluation is achieved. Online scores are automatically calculated by the Xuexitong platform, while offline scores are comprehensively evaluated by the teacher based on on-site operation specifications, design quality, data rationality, and report standardization.After each round of teaching, SPSS is used to analyze the correlation between each evaluation indicator and the final score, and inefficient or redundant indicators are removed. Anonymous student feedback is also collected, and the evaluation rules are iterated every semester using the action research method.

5 CONCLUSION

Against the backdrop of deepening Emerging Engineering Education construction, the reform of experimental courses for chemical engineering majors is no longer confined to superficial adjustments such as equipment renewal, content addition or deletion, or class-hour reallocation. Instead, it requires a fundamental transformation of the course form toward “smartification”. Taking the “Principles of Chemical Engineering Experiment” course at Guangdong University of Petrochemical Technology as a pilot, and addressing the three core long-standing pain points of traditional experimental teaching – “single method, fixed content, and lack of innovation” – a smart teaching system has been systematically built. This system uses a knowledge graph as the cognitive skeleton, virtual simulation as the pre-operation station, video resources as the preview vehicle, blended teaching as the implementation backbone, and multiple evaluation as the quality-assurance loop. The system breaks away from the outdated “instruct-first, follow-the-manual” mode, achieves an organic integration of the four links “theory → virtual → hands-on → reflection”, and forms a new experimental teaching ecology of “virtual-real combination, online-offline synergy, and data-driven continuous improvement” an embodiment of “unity of knowledge and action.”

Concretely, the reform has been implemented through the systematic upgrading of six modules. The full-cycle experimental video resource library transforms students’ pre-class preview from passive viewing into interactive cognition. The intelligent virtual simulation platform not only compensates for the limited number of physical equipment units but also enables automatic collection and feedback of operational behavior data, providing students with a safe space for “trial-error-correction-re-practice.” The knowledge graph built on knowledge engineering organically links theoretical nodes, experimental skills, and engineering applications scattered across unit operations (e.g., distillation, absorption, heat transfer), helping students establish a “point-line-surface” systematic knowledge structure. The task-driven blended experimental teaching model, guided by design-oriented preview tasks, focuses offline classroom time on proposal defense, comparative experiments, and deviation attribution analysis, truly shifting from a “teacher-centered” to a “student-centered” approach. The multi-dimensional tiered question bank system supports differentiated learning and personalized assessment. And the full-process, data-driven multiple evaluation system makes the learning process itself quantifiable, traceable, and improvable.

After multiple rounds of teaching practice and action research iterations, this reform scheme has effectively responded to the long-standing deficiencies of traditional experimental teaching. Students’ initiative in pre-class preview has significantly increased; the connection between virtual simulation and hands-on experiments has become smoother; the phenomenon of “template copying” in experiment reports has greatly decreased, replaced by data analysis and reflective discussion grounded in students’ own design plans. More importantly, in comparative and design-oriented experiments, students have begun to experience the research thinking path of “engineering problem → model assumption → parameter optimization → error analysis,” and their innovation literacy and practical abilities have been substantially strengthened. This reform path is applicable not only to the “Principles of Chemical Engineering Experiment” course; its progressive logic of “resource digitization → process datafication → evaluation multidimensionalization → teaching model smartification” also provides a replicable, scalable, and adaptable reference paradigm for other experimental courses in chemical engineering (e.g., Chemical Reaction Engineering Experiment, Separation Engineering Experiment) and even for broader practical teaching components in Emerging Engineering Education.

Looking ahead, the course team will further deepen exploration along the “data-driven” direction. On the one hand, based on knowledge graph data and learning behavior logs, lightweight AI models will be introduced to conduct learner profile analysis, enabling accurate identification of different student types “operation-difficulty type,” “theory-weak type,” “design-overambitious type” and to automatically push differentiated learning paths and remedial resources. On the other hand, the team will explore the auxiliary application of intelligent assessment in areas such as experiment report grading and preliminary judgment of design plan rationality, thereby reducing instructors’ repetitive workload and freeing them to focus on high-value face-to-face guidance and innovation inspiration. The ultimate goal is to move the experimental teaching of Principles of Chemical Engineering from a long-standing “experience-driven” mode toward a new paradigm of “accurate diagnosis-intelligent recommendation-continuous optimization” based on full-process data, and to cultivate more high-quality compound talents for the national chemical industry who possess solid engineering operation ability, systematic knowledge integration ability, and innovative problem-solving skills.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

FUNDING

The project was supported by Postgraduate Education Innovation Program of Guangdong University of Petrochemical Technology (2024).

REFERENCES

[1] Jesiek B K, Woo S E, Parrigon, et al. Development of a situational judgment test for global engineering competency. Journal of Engineering Education, 2020, 109(3): 470-490.
[2] Konstantinidou Evi, Ronny Scherer. Teaching with technology: A large-scale, international, and multilevel study of the roles of teacher and school characteristics. Computers & Education, 2022, 179: 104424.
[3] Ren Shuming, Xu Mengjie, Wang Qian. M&A and firm' s R&D: evidence from Chinese listed manufacturing firms. China Industrial Economics, 2017(7): 137-155.
[4] Hadgraft Roger G, Anette Kolmos. Emerging learning environments in engineering education. Australasian Journal of Engineering Education, 2020, 25(1): 3-16.
[5] Wankat Phillip C. Progress in reforming chemical engineering education. Annual review of chemical and biomolecular engineering, 2013(4): 23-43.
[6] Zhang Mingqian (John), Newton Cheryl, Grove Jason, et al. Design and assessment of a hybrid chemical engineering laboratory course with the incorporation of student-centred experiential learning. Education for Chemical Engineers, 2020(30): 1-8.
[7] Kolil Vysakh Kani, Krishnashree Achuthan. Virtual labs in chemistry education: A novel approach for increasing student's laboratory educational consciousness and skills. Education and Information Technologies, 2024, 29(18): 25307-25331.
[8] Brinson James R. Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers & Education, 2015, 87: 218-237.
[9] Zhang MJ, Newton C, Grove J, et al. Virtual and remote labs in education: A bibliometric analysis. Computers & Education, 2016, 98: 14-38.
[10] Chu Hui-Chun, Hwang Gwo-Haur, Tu Yun-Fang, et al. Roles and research trends of artificial intelligence in higher education: A systematic review of the top 50 most-cited articles. Australasian Journal of Educational Technology, 2022, 38(3): 22-42.
[11] Chen, Xieling, Xie Haoran, Zou Di, et al. Application and theory gaps during the rise of artificial intelligence in education. Computers and education: Artificial intelligence, 2020(1): 100002.
[12] Domingues Lucília, Rocha Isabel, Dourado Fernando, et al. Virtual laboratories in (bio) chemical engineering education. Education for Chemical Engineers, 2010, 5(2): e22-e27.
[13] Abdel-Badeeh M Salem, Elena V Mikhalkina, Anastasia Y. Nikitaeva. Establishment of smart education system in modern universities: Concept, technologies and challenges. International journal of education and information technologies, 2019, 13: 180-188.
[14] Wang Gang, Jing He. A bibliometric analysis of recent developments and trends in knowledge graph research (2013–2022). IEEE Access, 2024, 12: 32005-32013.
[15] Alkhatib Omar J. An interactive and blended learning model for engineering education. Journal of Computers in Education, 2018, 5(1): 19-48.