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Research on Innovative Practice Teaching Model for Chemical Engineering and Technology Major Driven by Integration of Virtual Simulation and Artificial Intelligence

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Abstract: The Chemical Engineering and Technology program is characterized by strong engineering orientation and practical application, where the quality of practical teaching directly impacts students 'professional competencies and engineering literacy development. However, current practical education still faces challenges such as incomplete process scenario representation, monotonous teaching methods, and outdated evaluation mechanisms due to safety risks, equipment costs, and limited teaching resources. To enhance practical teaching effectiveness, this study explores teaching reforms driven by the integration of virtual simulation and artificial intelligence. Based on analyzing practical teaching challenges in chemical engineering programs, we propose a competency-oriented practical teaching model featuring virtual-real integration and data-driven support. Implementation pathways are discussed through key areas including application of typical unit operations, curriculum system integration, faculty capacity building, and industry-academia collaboration. Research findings indicate that the fusion of virtual simulation and AI technologies significantly improves teaching authenticity, interactivity, and precision, while enhancing students' process understanding, operational skills, and problem-solving abilities. This study provides innovative insights for practical teaching reforms in chemical engineering disciplines.

Keywords: Chemical Engineering and Technology; Virtual Simulation; Artificial Intelligence; Practical Teaching; Teaching Model Innovation

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1. Introduction

The Chemical Engineering and Technology program exhibits pronounced engineering and practical characteristics. Its talent cultivation not only requires students to master chemical engineering principles and process knowledge but also emphasizes comprehensive competencies such as process comprehension, equipment operation, and process analysis. Practical teaching, as a critical link connecting theory with engineering applications, plays a pivotal role in the talent development system.

However, in practical teaching environments, constraints such as safety risks, equipment costs, and facility limitations often prevent the full demonstration of typical chemical processes. As a result, hands-on instruction tends to be reduced to isolated operations or verification experiments, leaving students with insufficient systematic understanding of real-world process flows. Moreover, traditional teaching methods primarily focus on step-by-step training without adequately cultivating engineering competencies like parameter adjustment and anomaly detection, which significantly limits educational effectiveness[1].

The advancement of virtual simulation and artificial intelligence technologies has opened new avenues to address these challenges. Virtual simulation enables the creation of dynamic environments that closely mimic real-world production scenarios, while AI facilitates learning process analysis and precise feedback mechanisms. This integration significantly enhances the visualization capabilities and personalization levels of practical teaching, driving the transformation of educational models toward smarter and more refined approaches.

2. Practical Teaching Challenges in Chemical Engineering and Technology Programs

2.1. Restricted Practical Settings and Incomplete Process Representation

Chemical production processes are characterized by high temperatures, high pressure, and significant hazards, making it challenging to replicate many typical processes in teaching environments. Current practical teaching methods primarily rely on simplified equipment or localized experiments[2]. While students can master basic operations, they lack comprehensive understanding of complete process flows, parameter coupling relationships, and system operational logic, resulting in a disconnect between theoretical knowledge and engineering practice.

2.2. Monotonous teaching methods and insufficient engineering competency cultivation

Traditional practical teaching primarily relies on instructor-led explanations and step-by-step operations, with students typically completing tasks within predefined procedures, leaving limited room for independent analysis and exploration. When encountering parameter fluctuations or abnormal operating conditions, students often struggle to make effective judgments and take appropriate actions, indicating that their capabilities remain at an operational level. Their engineering mindset and problem-solving skills require further enhancement.

2.3. Outdated evaluation methods fail to reflect the process of competency development

Current evaluations predominantly rely on experimental results and reports, with insufficient attention to students ‘performance during operational processes, making it difficult to comprehensively reflect their understanding of processes, parameter analysis, and problem-solving capabilities. Additionally, evaluations lack data support, hindering the provision of differentiated feedback, which is detrimental to teaching improvement and students’ personalized development.

3. Integration of Virtual Simulation and Artificial Intelligence to Drive the Construction of Practical Teaching Models

3.1. Restructuring Practical Teaching Objectives with a Focus on Competency Enhancement

The practice teaching model driven by the integration of virtual simulation and artificial intelligence requires fundamental restructuring at the instructional objectives level. Traditional practice teaching objectives predominantly focus on knowledge verification and basic skill training, emphasizing students’ mastery of experimental principles and ability to complete specified operations. However, under the new technological context, practice teaching objectives for chemical engineering and technology programs should be further expanded and deepened, highlighting comprehensive cultivation of students’ process comprehension capabilities, systematic analytical skills, problem-solving competencies, and proficiency in intelligent tool applications.

3.2. Restructuring the Practical Teaching Process with a Focus on Integrating Theoretical and Practical Elements

In instructional design, the practice-oriented teaching model integrating virtual simulation and AI should emphasize seamless integration across the entire process of "pre-class preparation – in-class training – post-class feedback," creating a more comprehensive learning cycle. During the preparatory phase, educators can utilize AI-powered teaching platforms to conduct preliminary analysis of students' existing knowledge base, assessing their understanding of chemical engineering principles, equipment structures, and process flows. Based on these insights, tailored learning resources—including process flow diagrams, equipment schematics, preview videos, and key challenge indicators—can be delivered to students[3].

4. Implementation Pathways of Teaching Models in Chemical Engineering and Technology Specialty

4.1. Organizing teaching implementation with typical chemical unit operations as the carrier

The practice-oriented teaching model driven by the integration of virtual simulation and artificial intelligence must ultimately be implemented through specific course content and training tasks to achieve tangible results. Given the strong process-oriented and operational nature of chemical engineering and technology programs, the implementation should prioritize selecting typical chemical unit operations such as distillation, absorption, heat transfer, fluid transportation, and reactions as teaching vehicles. This approach transforms abstract theoretical knowledge into visualized, actionable, and analyzable practical tasks. By developing simulation training projects aligned with job competencies, students can gain insights into process flows, understand equipment structures, and master operational logic within realistic production environments, thereby enhancing their comprehensive grasp of professional knowledge.

4.2. Promoting the Implementation of Teaching Models through Curriculum Integration

The implementation of this teaching model should not remain at the level of isolated platform usage or fragmented instructional demonstrations, but rather integrate deeply with the curriculum system of Chemical Engineering and Technology to form a cohesive and mutually reinforcing practical teaching chain. During implementation, virtual simulation and artificial intelligence technologies can be organically incorporated into core courses such as Chemical Engineering Principles, Chemical Process Technology, Chemical Equipment, and Chemical Safety Technology, ensuring seamless alignment in knowledge content, competency objectives, and practical tasks across disciplines. This approach not only prevents fragmented application of technical knowledge but also enables students to gradually develop systematic process understanding through continuous learning.

4.3. Ensuring Teaching Effectiveness through Teacher Competency Enhancement

The practice-oriented teaching model driven by the integration of virtual simulation and artificial intelligence imposes higher demands on educators 'pedagogical philosophies, professional competencies, and digital application skills. Instructors must not only possess expertise in chemical engineering and technology but also demonstrate proficiency in operating simulation platforms, analyzing teaching data, and adjusting instructional strategies through intelligent feedback mechanisms. Only when educators fully comprehend the core value of this model and effectively align it with curriculum objectives, instructional content, and students' developmental needs can teaching implementation achieve tangible outcomes.

5. Conclusion

Practical teaching in Chemical Engineering and Technology programs plays a vital role in talent development. However, current implementation faces challenges such as inadequate representation of real-world production scenarios, limited teaching methodologies, and outdated evaluation systems, which hinder students' engineering competencies and holistic development. The integration of virtual simulation and artificial intelligence offers innovative solutions. Virtual simulation overcomes constraints related to safety, cost, and spatial limitations to create dynamic practice environments mirroring actual production processes. Artificial intelligence leverages data analytics for learning diagnostics, real-time process feedback, and precise evaluation. This synergy facilitates the transition of practical education from experience-based, outcome-oriented approaches to intelligent, process-driven methodologies.

This study examines practical teaching challenges in chemical engineering and technology programs, analyzing current limitations while exploring an integrated virtual simulation and AI-driven practical teaching model with implementation strategies. Research demonstrates that this approach enhances students 'holistic understanding of process flows, improves targeted and interactive operational training, and facilitates more objective and comprehensive teaching evaluations.

Disclosure statement

The author declares no conflict of interest.

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