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Exploration of Integrated Theory and Practical Teaching Mode for Chemical Engineering Principles under the Emerging Engineering Background

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Abstract: The construction of emerging engineering disciplines focuses on industrial transformation and upgrading as well as talent demands in emerging chemical sectors, putting forward innovation requirements for the traditional classroom teaching of Chemical Engineering Principles. As a core course linking basic theories and engineering applications for chemical majors, it is confronted with prevalent practical difficulties including abstract theoretical formulas, disconnection between classroom lectures and industrial realities, and separation of theoretical learning from practical application. Based on the talent cultivation objectives of emerging engineering education, this paper takes integrating theoretical knowledge into the classroom and connecting classroom teaching with engineering scenes as the core idea, and constructs a new integrated teaching mode from four dimensions: reconstruction of teaching content, innovation of classroom teaching methods, integrated design of theory and practice, and diversified assessment mechanisms. Classroom practice is carried out around typical unit operations such as fluid transportation, heat transfer, and distillation. Practical results show that the integrated classroom can reduce students' difficulty in understanding theories and strengthen their engineering thinking, meeting the employment standards of emerging engineering industries including the new energy chemical industry and the green chemical industry. It can provide references for classroom reform of similar engineering majors.

Keywords: Emerging engineering; Chemical Engineering Principles; Classroom teaching; Integration of theory and practice; Teaching mode

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1. Introduction

With the rapid development of emerging industries such as new energy materials, carbon capture, utilization, and storage (CCUS), the fine green chemical industry, and the high-end coal chemical industry, the construction of emerging engineering disciplines has been continuously deepened. Talent cultivation in university chemical majors has transformed from traditional process-oriented personnel to innovative interdisciplinary engineering technicians [1]. Covering three fundamental laws of fluid mechanics, heat transfer, and mass transfer, as well as classic unit operations including distillation, extraction, drying, and filtration that run through the whole modern chemical industrial chain, Chemical Engineering Principles is an indispensable core course in chemical engineering education [2].

Traditional teaching modes have long relied on textbook lectures. Centering on formula derivation, parameter calculation, and equipment structure explanation, teachers attach importance to the integrity of theoretical systems while lacking integration of industrial site scenarios. Students can only memorize calculation formulas mechanically and are unable to cope with practical problems such as engineering optimization, process energy saving, and equipment fault diagnosis [3]. The emerging engineering concept emphasizes interdisciplinary integration, industry-education integration, and cultivation of engineering innovation ability, forcing classrooms to break the rigid "pure theoretical lecture" mode and promote deep integration of classroom teaching, theoretical knowledge, and engineering cases. Against this backdrop, exploring a classroom integrated teaching mode adapted to emerging engineering education requirements and optimizing classroom organization and knowledge presentation has become a key task of current curriculum teaching reform.

2. Existing teaching pain points of Chemical Engineering Principles from the perspective of emerging engineering

2.1. Abstract theoretical knowledge, classroom lectures disconnected from industrial frontiers

A large number of empirical formulas and dimensionless correlations in Chemical Engineering Principles are summarized from engineering experiments. Abstract concepts such as Reynolds number, Prandtl number, and mass transfer unit height cannot be visualized through pure verbal explanation [4]. The update speed of existing textbooks lags behind the development of emerging engineering industries. Classroom cases mostly adopt traditional petroleum refining processes, while materials for emerging technologies such as CCUS carbon capture and separation, membrane seawater desalination, and lithium battery slurry drying are scarce. Students fail to perceive the application value of professional knowledge in cutting-edge chemical fields, leading to weak learning initiative.

2.2. Separation of theory and classroom practice, lack of immersive engineering scenarios in class

Conventional classrooms are limited to blackboard writing and PPT presentation. Theoretical study, experimental operation, and curriculum design are carried out separately. There is no auxiliary teaching in class such as small-scale simulation demonstration, process video decomposition, and equipment structure disassembly [5]. When learning theories in class, students cannot directly match them with the operation principles of industrial equipment; after entering experimental sessions, they forget basic theoretical logic, resulting in a disconnect of "understanding theories in class but unable to apply them in practice," which fails to meet the requirements of cultivating engineering literacy under emerging engineering education.

2.3. Single classroom teaching method, students receive knowledge passively

Most classrooms still adopt indoctrination teaching of "teacher lecture + example calculation," lacking interactive links such as problem inquiry, group discussion, and engineering scheme design. Classroom teaching is oriented to exam problem-solving, focusing on calculation exercises while ignoring core emerging engineering cultivation contents such as process optimization, safety control, and green energy conservation. It is difficult to cultivate students' innovative design and engineering judgment abilities [6].

2.4. Course assessment focuses on written examinations, fails to measure comprehensive application ability

Final written examinations account for the majority of total course scores. Assessment contents center on formula application and numerical calculation, while process indicators such as classroom performance, scheme discussion, and process optimization design take up a tiny proportion. The assessment orientation encourages students to memorize mechanically, deviating from the talent cultivation orientation of emerging engineering education that values practice and innovation [7].

3. Construction ideas of theory-classroom deep integrated teaching mode oriented to emerging engineering

Based on the core education connotation of emerging engineering featuring innovation, interdisciplinarity, green development and practical application, and following the construction logic of "theories anchoring knowledge points, classrooms carrying application points and industries providing extended points," this paper constructs a four-in-one classroom teaching system integrating content, teaching methods, scenarios and assessment. Industrial new technologies and engineering cases as well as simulation resources are embedded in pre-class, in-class and after-class links by layers [8].

3.1. Reconstruction of teaching content: Two-way integration of classic theories and emerging engineering frontiers

Retaining the original chapter framework of the course and the basic theoretical system of fluid flow, heat transfer, and mass transfer, supplementary emerging industrial contents are added to form a three-level classroom teaching content list of "basic theories + traditional processes + emerging chemical applications" [9].

(1) Fluid Transport Chapter: Based on the theory of pipeline resistance calculation for centrifugal pumps, introduce cases of energy-saving transformation of new energy electrolyte conveying pipelines and domestic high-pressure raw material conveying equipment, and explain the practical application of pipeline optimization theories in cost and energy reduction.

(2) Heat Transfer Chapter: Centering on the heat efficiency calculation formula of heat exchangers, carry out classroom teaching combined with emerging engineering hot topics such as waste heat recovery of photovoltaic energy storage systems and incineration waste heat utilization of industrial solid waste.

(3) Distillation and Absorption Chapter: Based on gas-liquid mass transfer theories, integrate cutting-edge processes including CO_2 absorption and separation in coal-fired power plants and rectification and purification of bio-based products to fill the gap of frontier content in textbooks. During lesson preparation, teachers decompose frontier materials into 5–10-minute short cases and embed them into corresponding knowledge points to realize a natural connection between textbook

theories and emerging engineering industries.

3.2. Innovation of classroom teaching methods: Diversified teaching to realize theoretical application in class

Abandon single blackboard teaching, and integrate problem-oriented teaching, group discussion teaching, and simulation-aided teaching to build interactive integrated classrooms [10].

(1) Problem-driven theory introduction

Set an engineering question at the beginning of each class to derive theoretical formulas [11]. For example, before explaining the theory of relative volatility in distillation, raise the question: “Why is multi-column continuous distillation adopted instead of simple distillation in bioethanol purification?” Guide students to study theories with doubts and understand the engineering demands behind the formation of theories.

(2) Group discussion in class to deepen theoretical application

Arrange one class hour of special discussion at the end of each unit. Divide the class into groups to discuss energy-saving transformation and process optimization. After learning the drying unit, students discuss optimization schemes for lithium electrode slice drying and put forward improvement ideas based on drying rate theories. Teachers comment on the correctness of theories one by one, consolidating theories through classroom speculation.

(3) Visual teaching assisted by simulation software

With the help of chemical simulation software and 3D equipment models, project dynamic images such as internal flow field changes of centrifugal pumps, heat exchange processes of tube-and-shell heat exchangers, and gas-liquid two-phase flow inside distillation towers in class. Abstract concepts such as Reynolds number, convective heat transfer coefficient, and tower mass transfer mechanism are converted into dynamic pictures to resolve the difficulty of obscure theories.

3.3. Extension of classroom scenarios: Building integration channels between classrooms and engineering sites

Expand classroom boundaries relying on online and offline resources to extend theories from textbooks to industrial sites [12]

First, introduce enterprise real-scene short videos and insert on-site shooting materials of refining and new energy chemical plants in class to review textbook theories against equipment operation processes in videos. Second, utilize cloud virtual factory platforms; students log into online simulation factories within limited class hours to fine-tune equipment parameters and intuitively observe the impact of parameter changes on process indicators, verifying theoretical calculation formulas through practical operation. Third, carry out short-hour cloud online lectures with enterprise engineers regularly, who explain the practical application of unit operation theories combining actual posts to strengthen the industry-education integration attribute of emerging engineering education.

3.4. Integration of assessment system: Building a process-based multi-dimensional classroom evaluation system

In line with emerging engineering talent evaluation standards, optimize the composition of course scores. The total score consists of final written examination (50%) + classroom process assessment (35%) +

extracurricular extended achievements (15%) [13].

(1) Classroom process assessment: Scoring based on the quality of classroom discussions, in-class small assignments of process optimization and simulation operation performance, focusing on flexible theoretical application ability.

(2) Extracurricular extended achievements: Including small process research reports and unit operation optimization design schemes. Students are encouraged to select topics around the green chemical industry and low-carbon technology, matching the requirements of cultivating innovation under emerging engineering education.

(3) Final written examination: Reduce the proportion of pure mechanical calculation questions and add engineering application questions, such as selecting appropriate absorption equipment for CCUS processes and illustrating the theoretical basis, to assess the integration capacity of theories and industries.

4. Practical application and effect analysis of integrated teaching mode

This teaching mode has been piloted for two academic years in the course Chemical Engineering Principles for the 2024 and 2025 Chemical Engineering and Technology majors of our university. Parallel classes of the same grade were selected for a controlled study: the control group adopted the traditional lecture mode while the experimental class adopted the new theory-classroom integrated mode.

In terms of classroom performance, the experimental class saw a significant increase in classroom attention rate, number of active questions, and participation in discussions. Students no longer merely focus on formula solving and can independently analyze theoretical application scenarios combined with frontier chemical cases. Final score data show that the average score of application questions in the experimental class is 12.7% higher than the control group. The proportion of students choosing low-carbon and new energy topics in curriculum design rose from 21% before the reform to 65%. Post-class questionnaire results indicate that 87.3% of students believe the integrated classroom reduces the difficulty of theoretical learning, enables them to clearly understand the application prospects of Chemical Engineering Principles in emerging engineering industries, and significantly enhances professional identity [14].

Deficiencies were also found during practice: the update speed of frontier case resources is limited by access to industrial information, and some teachers lack reserves of emerging engineering technologies [15]. Subsequent measures include establishing curriculum teaching and research teams to regularly cooperate with chemical enterprises and update case libraries, as well as organizing industrial training for teachers to make up for deficiencies in frontier knowledge.

5. Safeguard measures to optimize the integrated teaching mode

5.1. Establishing curriculum teaching and research teams to coordinate classroom resource construction

Set up curriculum construction teams composed of professional teachers and senior enterprise engineers to carry out collective lesson preparation regularly. Team members sort out emerging engineering cases and classroom simulation materials as well as discussion topics by division of labor, and revise classroom teaching handouts year by year to ensure teaching contents keep pace with the iteration of chemical industries.

5.2. Improving online teaching resource library to support fragmented classroom teaching

Upload unit operation simulation micro-lessons, popular science videos of frontier technologies, and after-class extended thinking questions on the online course platform. Students preview theories and industrial materials before class, saving theoretical explanation time in class and reserving more class hours for discussion and application teaching, forming a closed-loop integration system of pre-class, in-class, and after-class links.

5.3. Deepening university-enterprise collaboration to enrich real-scene classroom resources

Establish regular cooperation with local fine chemical and new energy material enterprises. Enterprise engineers are invited to deliver special lectures on campus periodically. Process optimization problems encountered in production are collected and transformed into classroom discussion topics, ensuring classroom content originates from and serves industries.

6. Conclusion

The core of classroom reform of Chemical Engineering Principles under the background of emerging engineering education lies in breaking away from the shackles of pure theoretical lectures, promoting in-depth integration of theory and practice based on theoretical contents, taking classroom scenarios as carriers and industrial demands as guidance. The integrated teaching mode constructed through reconstructing teaching contents, innovating diversified teaching methods, expanding real-scene teaching scenarios, and reforming multi-dimensional assessment can effectively solve traditional drawbacks including abstract theories and disconnection from industrial frontiers. While consolidating students' basic chemical theories, it cultivates their engineering innovation and green chemical thinking. In subsequent teaching, we need to keep up with the development trends of emerging engineering industries, continuously update classroom cases and teaching resources, optimize integrated classroom details, and deliver interdisciplinary talents with solid theories, engineering literacy, and innovative awareness for the chemical industry of the new era.

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Disclosure statement

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