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Reform and Practice of Comprehensive Experiment Teaching in Water Pollution Control Engineering based on Project-Driven Approach

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ABSTRACT

Aiming at the prominent problems existing in the practical teaching of environmental engineering majors in application-oriented undergraduate colleges, such as outdated experimental contents, excessive proportion of verification experiments, disconnection from engineering practice, and insufficient student initiative, this paper takes the Comprehensive Experiment of Water Pollution Control Engineering course at Chengdu Technological University as the research object, and systematically explores the curriculum reform path based on Project-Based Learning (PBL). A project-driven teaching system oriented by real wastewater treatment engineering problems, supported by project clusters, and targeting competency cultivation was constructed. Four progressive experimental projects were designed: activated sludge performance diagnosis, aeration system optimization, process operation and control, and combined process design. Students' experimental operation ability, engineering problem-solving ability, teamwork ability, and professional competence were significantly enhanced, forming practical teaching experience that can be promoted, which can provide useful reference for the project-driven teaching reform of environmental majors in similar institutions.

KEYWORDS

Project-Based Learning; Practical Teaching; Water Pollution Control Engineering; Comprehensive Experiment.

1. INTRODUCTION

In the field of environmental engineering, with the deepening promotion of China's dual-carbon strategy and the continuous strengthening of ecological civilization construction, the wastewater treatment industry is undergoing a profound transformation from meeting discharge standards to improving quality and efficiency. New technologies and processes such as precise aeration control, intelligent dosing systems, and sludge reduction and resource recovery are constantly emerging, putting forward higher requirements for the cultivation of environmental engineering professionals in universities [1]. The traditional experimental teaching model dominated by verification experiments, in which students mechanically follow predetermined steps without space for independent design and innovative exploration, can no longer meet the rapidly developing needs of industry technology. Systematic teaching reform is urgently needed to cultivate high-quality application-oriented talents with solid theoretical foundations, excellent practical skills, and good professional competence [2].

Project-Based Learning (PBL) is a student-centered teaching method that uses real projects as carriers and problem-solving as orientation [3]. Its core idea is to integrate learning content into projects with practical significance, enabling students to actively construct knowledge, develop skills, and cultivate competencies in the process of completing projects. Project-based teaching emphasizes "Learning by Doing", driving students' deep learning through complex tasks in authentic contexts, and promoting the coordinated development of knowledge, ability, and literacy [4]. Introducing project-based teaching into the practical teaching of environmental engineering majors has the following important values: First, it achieves close alignment between teaching content and engineering practice, using real wastewater treatment engineering problems as project backgrounds to enhance the authenticity and relevance of learning; Second, it promotes the transformation of students from passive acceptance to active inquiry, cultivating independent learning and problem-solving abilities in the stages of project scheme design, experimental operation, and data analysis; Third, it promotes the organic integration of knowledge transmission and ability cultivation, enabling students to naturally acquire professional knowledge and skills in the process of completing projects; Fourth, it cultivates teamwork and engineering thinking, as projects are usually carried out in groups, allowing students to exercise communication and teamwork abilities through division of labor and collaboration; Fifth, it promotes deep integration of industry and education, as real engineering cases from enterprises provide rich materials for project design, and the participation of enterprise mentors in project guidance enhances the engineering nature of teaching [5].

Comprehensive Experiment of Water Pollution Control Engineering is a core intensive practical course for environmental science and engineering majors, playing an irreplaceable role in cultivating students' engineering practical abilities. This study takes this course at Chengdu Technological University as the research object, systematically exploring the practical teaching reform path based on project-driven teaching, which has important theoretical value and practical significance for deepening the teaching reform of environmental majors in application-oriented undergraduate colleges, improving talent cultivation quality, and serving regional economic and social development.

2. THEORETICAL FOUNDATION SYSTEM

As shown in Fig. 1, the theoretical foundations closely related to project-driven teaching include three types: constructivist learning theory, CDIO (conceive-design-implement-operate) engineering education model, and OBE (outcome-based education) concept.

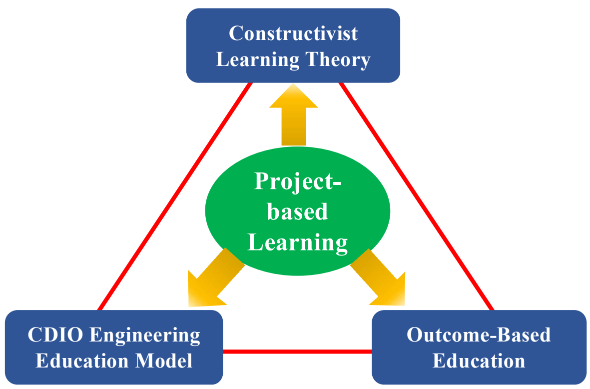

Fig. 1 Theoretical foundation system of project-driven teaching

Constructivist learning theory: Constructivist learning theory holds that knowledge is not passively received, but actively acquired by learners through meaning construction in certain contexts, with the help of others (teachers and learning partners), using necessary learning materials [6]. Project-driven teaching is the specific application of constructivist learning theory in practical teaching. In project-driven teaching, students face real wastewater treatment engineering problems, and through active inquiry activities such as literature review, scheme design, hands-on experiments, and data analysis, they construct deep understanding of water pollution control engineering knowledge in interaction with the environment, peers, and teachers, achieving cognitive leaps from "knowing" to "being able to do" to "understanding".

CDIO engineering education model: The CDIO (conceive-design-implement-operate) engineering education model emphasizes using engineering projects as carriers to cultivate students' abilities in engineering conception, design, implementation, and operation [7]. Project-driven teaching is highly compatible with the CDIO concept. Through the complete project process of "project release-scheme design-experiment implementation-achievement evaluation", students identify engineering problems in the conception stage, formulate solutions in the design stage, complete experimental operations in the implementation stage, and analyze and evaluate treatment effects in the operation stage, systematically cultivating engineering practical abilities.

OBE outcome-based education concept: The OBE (outcome-based education) concept emphasizes orienting toward students' learning outcomes and reverse-designing teaching objectives and processes [8]. In project-driven teaching, the competency goals that students should achieve through project learning are first clarified (such as experimental operation ability, data analysis ability, engineering design ability, etc.), then project contents and implementation processes are designed accordingly, and finally, diversified evaluation is used to verify the achievement of goals, forming a closed loop of "goal-implementation-evaluation-improvement" to ensure the quality of talent cultivation.

The three theories are integrated and synergistic in project-driven teaching [9]. Constructivism provides the cognitive mechanism for learning occurrence, CDIO provides the methodological framework for engineering ability cultivation, and OBE provides the operational path for goal setting and quality assurance [10]. Together, they constitute the theoretical foundation system for project-driven teaching reform.

3. NECESSITY OF PROJECT-DRIVEN REFORM

Comprehensive Experiment of Water Pollution Control Engineering is a required professional course for environmental science and engineering majors, usually offered in the junior year. Through years of teaching reflection, student questionnaire surveys, and peer expert reviews, the following prominent problems in traditional experimental teaching were systematically identified:

a.Outdated experimental content, disconnected from industry development. Traditional experimental projects are mostly classical verification experiments, such as free sedimentation experiments and coagulation experiments. The experimental content updates slowly and fails to timely reflect new technologies, new processes, and new standards in the wastewater treatment industry, resulting in a large gap between what students learn and actual engineering applications.

b.Excessive proportion of verification experiments, insufficient comprehensiveness and design. Among the original six experimental projects, verification experiments accounted for five (83.3%), while comprehensive experiments accounted for only one (16.7%). Students mechanically follow predetermined steps, lacking space for independent design and innovative exploration, making it difficult to cultivate the ability to solve complex engineering problems.

c.Single teaching model, insufficient student initiative. Traditional teaching mainly follows the pattern of "teacher demonstration-student imitation-report writing". Students passively receive knowledge with limited opportunities for active inquiry and independent thinking, and their learning enthusiasm and creativity are not fully mobilized.

d.Disconnection from engineering practice, shallow integration of industry and education. Experimental teaching is limited to on-campus laboratories, lacking immersion in real engineering scenarios. Students find it difficult to establish complete engineering concepts and lack intuitive understanding of process regulation, fault diagnosis, and optimized operation in actual enterprise operations.

e.Single evaluation method, insufficient competency orientation. Traditional evaluation focuses mainly on experimental reports, emphasizing result assessment while neglecting process evaluation and competency evaluation, making it difficult to comprehensively reflect students' experimental operation standardization, data analysis ability, and problem-solving ability.

4. REFORM DESIGN AND IMPLEMENTATION

4.1 Construction of Project-Driven Teaching System

Based on the project-driven teaching concept, a "problem orientation-project carrier-competency goal-support guarantee" four-in-one teaching system was constructed, as shown in Fig. 2.

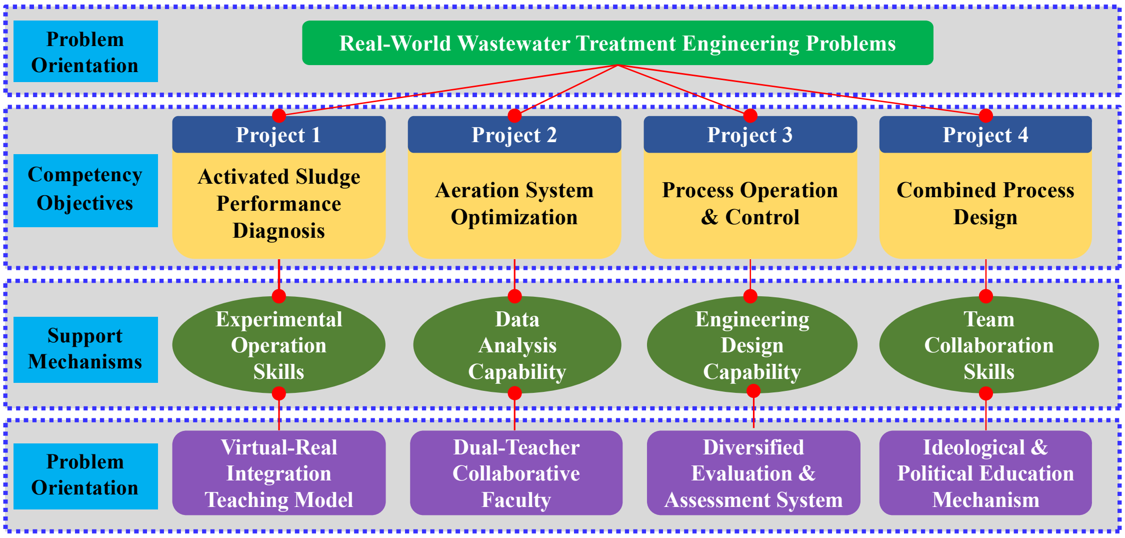

Fig. 2 Architecture of project-driven teaching system

This system is oriented by "real wastewater treatment engineering problems", supported by four progressive experimental projects, targeting competencies such as experimental operation, data analysis, engineering design, and teamwork, and supported by a virtual-real integrated teaching model, dual-teacher collaborative faculty team, diversified evaluation and assessment system, and ideological and political education integration mechanism, forming a project-driven teaching framework with clear goals, clear structure, and orderly operation.

4.2 Project Cluster Design and Characteristics

Project design follows the following principles: First, the authenticity principle, where projects originate from real enterprise engineering problems with clear engineering backgrounds and application value; Second, the comprehensiveness principle, where each project covers the comprehensive application of multiple knowledge points, avoiding simple training of single skills; Third, the progressiveness principle, where project difficulty and complexity increase step by step, forming a gradient for competency cultivation; Fourth, the openness principle, where project solutions are not unique, encouraging students' independent innovation and diversified exploration; Fifth, the collaboration principle, where projects are carried out in groups to cultivate teamwork abilities.

Centering on the core goal of cultivating the ability to solve complex water pollution control engineering problems, four progressive experimental projects were designed, as shown in Table 1. Project 1 focuses on cultivating basic experimental operation and data analysis abilities; Project 2 focuses on cultivating parameter optimization and scheme design abilities; Project 3 focuses on cultivating process operation control and comprehensive problem-solving abilities; Project 4 focuses on cultivating system design and innovative thinking abilities. Compared with traditional verification experiments, project-driven experiments have significant advantages in problem authenticity, student initiative, comprehensiveness, design, teamwork, engineering alignment, and competency cultivation.

Table 1. Composition of project-driven experimental project cluster

No.	Project Name	Project Type	Engineering Problem Source	Hours Allocation
1	Activated Sludge Performance Diagnosis	Comprehensive	Sludge bulking problem in a wastewater treatment plant	5
2	Aeration System Optimization	Design	Excessive aeration energy consumption in a wastewater treatment plant	5
3	Process Operation and Control	Comprehensive	Effluent COD exceeding standard in a wastewater treatment plant	6
4	Combined Process Design	Design	Wastewater treatment scheme design for an industrial park	6

4.3 Project Implementation Process

A seven-step implementation process was established, as shown in Fig. 3.

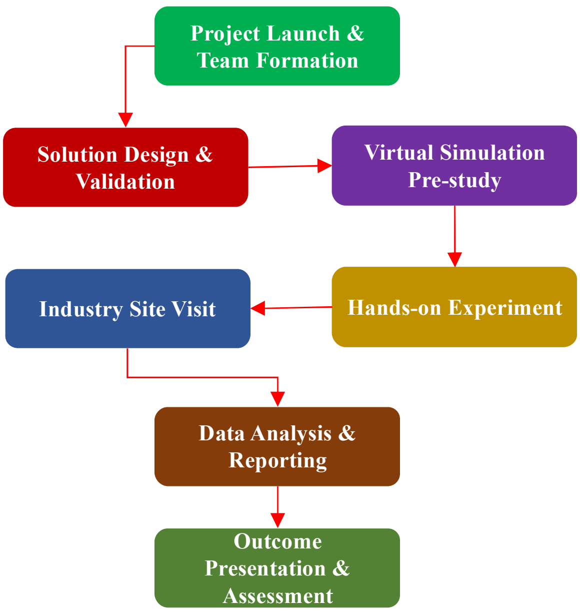

Fig. 3 Implementation process of project-driven teaching

Step 1: Project Launch & Team Formation. Teachers release project background materials and task requirements, including engineering problem descriptions, known conditions, expected goals, and evaluation criteria. Students form groups freely (3-4 persons/group) and clarify internal division of labor.

Step 2: Solution Design & Validation. Students review literature to understand relevant process principles and engineering cases, and design experimental schemes, including experimental purposes, principles, steps, required instruments and equipment, and expected results. Each group presents their scheme, and teachers and enterprise mentors jointly demonstrate the feasibility and scientific validity of the scheme, providing modification suggestions.

Step 3: Virtual Simulation Pre-study. Students conduct process operation rehearsals through the virtual simulation platform, familiarizing themselves with equipment operation procedures, parameter adjustment methods, and safety precautions, reducing operational risks in physical experiments and improving experimental efficiency.

Step 4: Hands-on Experiment. Students conduct physical device operations according to the demonstrated schemes, including SBR reactor parameter regulation, AAO process operation, activated sludge evaluation, and aeration equipment oxygenation capacity measurement. Teachers and enterprise mentors provide on-site guidance, promptly answering operational questions.

Step 5: Industry Site Visit. Students visit Chengdu Keya Wastewater Treatment Plant for field learning, observing real process operation, participating in parameter adjustment, and analyzing engineering cases, comparing laboratory bench-scale experiments with engineering practice to establish complete cognition from laboratory to engineering site.

Step 6: Data Analysis & Reporting. Students organize, process, and analyze experimental data, use professional software to draw charts, and write project reports, including experimental processes, data analysis, result discussion, and conclusion suggestions.

Step 7: Outcome Presentation & Assessment. Each group conducts PPT presentations, demonstrating project achievements, and receives questions and evaluations from teachers, enterprise mentors, and classmates. Through multi-subject evaluation, students' knowledge mastery, competency performance, and literacy development are comprehensively assessed. The seven-step process forms a complete project closed loop, in which students achieve the organic unity of knowledge construction, competency development, and literacy enhancement.

4.4 Project Evaluation Mechanism

A diversified evaluation system combining process evaluation (50%) and achievement evaluation (50%) was established. Process evaluation includes scheme design quality (15%), experimental operation standardization (15%), teamwork performance (10%), and classroom participation (10%). Achievement evaluation includes data analysis and processing (20%), report writing quality (20%), and presentation effectiveness (10%). Meanwhile, multiple evaluation subjects including on-campus teachers, enterprise mentors, peer group evaluation, and student self-evaluation were introduced. Enterprise mentors focus on evaluating students' engineering thinking ability and professional competence; peer group evaluation promotes teamwork and mutual learning; student self-evaluation cultivates reflection ability and independent learning awareness. In addition, Project Evaluation Standards were formulated to conduct quantitative evaluation from dimensions such as scheme design, experimental operation, data processing, result analysis, report writing, and presentation, ensuring the scientific validity and operability of evaluation.

4.5 Support and Guarantee System

A three-layer progressive teaching model of “virtual simulation preview + physical device operation + enterprise site observation” was constructed to provide technical support for project implementation. The virtual simulation platform provides immersive learning experiences, physical devices cultivate practical operation skills, and enterprise sites establish engineering concepts.

A “on-campus teacher + enterprise mentor” dual-mentor collaborative education mechanism was established. The on-campus teacher team consists of three “dual-qualification and dual-competency” teachers responsible for theoretical guidance and experimental teaching; the enterprise mentor team consists of two intermediate engineers responsible for field teaching and engineering case guidance. Dual mentors teach an average of 4 hours per semester, achieving synchronous updating of teaching content and industrial needs.

Ideological and political elements such as professional competence, environmental protection responsibility, and craftsmanship spirit were organically integrated into various stages of project teaching. Through case introductions such as “wastewater treatment concerns people’s livelihood and welfare”, the concept of ecological civilization was established; through emphasizing operational standardization and data accuracy, craftsmanship spirit was cultivated; through group collaboration and troubleshooting, teamwork and scientific attitude were cultivated.

5. IMPLEMENTATION EFFECTIVENESS

Through questionnaire surveys and competency assessments, students showed significant improvement in six dimensions: experimental operation ability, data analysis ability, engineering problem-solving ability, teamwork ability, innovative design ability, and professional competence. Specifically, the average score of experimental operation ability assessment increased from 65.8 to 89.5; the average score of data analysis ability assessment increased from 70.5 to 85.2; the average score of engineering problem-solving ability assessment increased from 55.7 to 82.4; the average score of teamwork ability assessment increased from 80.4 to 96.8; the average score of innovative design ability assessment increased from 50.8 to 80.2; and the average score of professional competence assessment increased from 75.2 to 96.5.

Through end-of-semester student teaching evaluations and course satisfaction surveys, students’ overall satisfaction with the course increased from 78.5% before the reform to 94.8% after the reform, with significant improvements in recognition of project content practicality, teaching model innovation, enterprise practice value, and evaluation fairness. Students generally reported that project-driven teaching made experiments meaningful, that they truly understood process principles through doing projects, and that enterprise field teaching left a deep impression.

Furthermore, the course construction experience was promoted among environmental majors within and outside the university, providing reference for the reform of courses such as Solid Waste Treatment and Disposal Experiment and Air Pollution Control Engineering Comprehensive Experiment. The course team participated in three university-level teaching reform projects, published five related teaching reform papers, guided students to publish six papers, applied for ten college student innovation training program projects and laboratory open fund projects, authorized eight patents, and won more than 20 various discipline competition awards, forming replicable project-driven teaching experience.

6. SUMMARY

Project-driven teaching effectively solved the prominent problems existing in the traditional Comprehensive Experiment of Water Pollution Control Engineering course, such as outdated experimental content, excessive proportion of verification experiments, disconnection from engineering practice, and insufficient student initiative, achieving the transformation from verifying principles to solving problems, from passive acceptance to active inquiry, and from single skills to comprehensive abilities. Students' comprehensive abilities were significantly enhanced, providing strong support for engineering education accreditation of the environmental science and engineering major. In the future, the course team will continue to deepen project-driven teaching reform, expand project sources and types, improve virtual simulation resources, optimize evaluation index systems, and strive to build the course into a provincial first-class undergraduate course, providing demonstration and reference for the practical teaching reform of environmental majors in similar institutions.

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