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RESEARCH ARTICLE

TEACHING REFORM AND PRACTICE EXPLORATION OF THE “WATER QUALITY ENGINEERING” COURSE

Lu Haijun[1], Wei Na[1*], Dong Yiqie[1]

[1] School of Civil Engineering and Architecture, Wuhan Polytechnic University, 430023, Wuhan, China

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Corresponding Author
lhj@whpu.edu.cn
weina31@126.com
dyq_whpu@163.com

ABSTRACT

To substantially enhance the teaching effectiveness of the "Water Quality Engineering" course, our university has developed a specialized case library and explored the integration of ideological and political elements into case-based teaching. By systematically combining traditional and emerging interdisciplinary engineering cases, we adhere to principles such as authenticity, theoretical-practical integration, and systematic stratification to innovate teaching methodologies. Practical data demonstrates that this reform has significantly enhanced students' engineering application capabilities and innovative thinking. The Course assessment excellence rate has increased to 21%, while the adoption rate of innovative design proposals has risen to 30%, providing replicable practical experience for the teaching reform in the water supply and drainage engineering specialty.

1. INTRODUCTION

Against the backdrop of advanced engineering education development, the training of water supply and drainage engineering professionals faces new challenges and requirements. The national initiative for new engineering education emphasizes cultivating innovative, interdisciplinary, and application-oriented talents (Di et al., 2022). As a core course in water supply and drainage science and engineering, "Water Quality Engineering" serves as the primary arena for cultivating high-level professionals in the new era, where teaching quality directly impacts students 'professional competence development (Liang et al., 2020). Traditional teaching methods account for over 80% of instruction (according to 2020 teaching logs), while the error rate in students' process design reaches 35% (based on 2020 course design statistics), highlighting issues such as disconnection between teaching and engineering practice, as well as insufficient cultivation of students 'innovative abilities. To address these challenges, case-based teaching has gradually become a key direction for educational reform in water supply and drainage science and engineering (Huang et al., 2020; Li & Tian, 2018). This paper elaborates on case-driven teaching reforms and practices through the construction and gradual implementation of a "Water Quality Engineering" case teaching repository, highlighting the repository's distinctive features and innovations, aiming to provide references for curriculum reform in related courses.

2. CONSTRUCTION OF CASE TEACHING CASE LIBRARY

2.1. Construction Principles

Emphasizing the authenticity and timeliness of case studies: The credibility of a case library forms the foundation for enhancing teaching effectiveness and practical engineering education. Therefore, selecting representative engineering cases that reflect the latest professional development trends is crucial. For instance, the selected urban water treatment plant upgrade project in the case library authentically demonstrates the technological transformation needs of traditional water supply processes against the backdrop of China's worsening water source pollution and stricter water quality standards. Additionally, the industrial park heavy metal wastewater treatment project effectively illustrates the challenges of heavy metal contamination and subsequent solutions in engineering practice. These cases provide students with authentic engineering scenarios, enabling them to conduct in-depth analyses based on real-world engineering contexts and thereby improve their practical engineering skills.

Enhancing the integration of theory and practice: Each case study is closely tied to the theoretical knowledge covered in class. For instance, the water treatment plant upgrade case not only involves traditional treatment processes such as coagulation, sedimentation, filtration, and disinfection, along with the enhancement of these processes, but also encompasses the chemical oxidation, adsorption, and microbial metabolism theories underlying the ozone-biological activated carbon advanced treatment process. Through case analysis, students can effectively combine theoretical knowledge with practical engineering challenges, thereby deepening their understanding and mastery of the theoretical aspects.

Implementing a tiered knowledge framework: Cases are categorized into three levels based on their characteristics and required knowledge mastery—basic, advanced, and extended. Basic-level cases, such as single sedimentation process optimization, help students grasp fundamental process principles and operations. Advanced-level cases, like comprehensive wastewater treatment plant upgrades, involve the integration and optimization of multiple processes, fostering students' ability to apply knowledge comprehensively. Extended-level cases, such as the application of low-carbon technologies and smart water management systems in water quality engineering, guide students to explore industry frontiers and broaden their knowledge horizons.

Prioritizing disciplinary development: During case selection, we emphasize integrating emerging fields such as smart water management, ecological restoration, and low-carbon water treatment. For instance, smart water management case studies, when combined with advanced technologies like IoT, big data, and GIS, significantly boost student engagement and deepen their understanding of industry trends.

Enhancing holistic competency development: During case analysis and discussion sessions, we emphasize guiding students to explore the interplay between technological, economic, environmental, and social dimensions. For instance, in the wastewater treatment plant upgrade case study, beyond focusing on process technology improvements, we guide students to analyze the ecological benefits of the project for surrounding water bodies, as well as the economic impacts of construction and operational costs. This approach cultivates students' engineering ethics and sustainable development awareness.

2.2. Case Selection and Design

2.2.1. Case Studies in Traditional Engineering Fields

Urban Water Treatment Plant Modernization Project: As population growth and industrial development have caused increasingly severe water source pollution in a city, the conventional treatment processes of the original water plant could no longer meet the latest effluent quality requirements specified in the "Hygienic Standard for Drinking Water". This case study details the implementation of an advanced ozone-biological activated carbon treatment process, along with enhanced measures for existing processes including coagulation, sedimentation, filtration, and disinfection. In classroom teaching design, students are required to analyze the shortcomings of the original process and conduct relevant literature reviews before class. During the lesson, students analyze process comparisons before and after modernization, examine the plant's layout and elevation arrangements, and evaluate changes in effluent quality data. The principles and key parameters of the treatment process are explained through animated demonstrations and process videos, followed by student discussions on alternative solutions. Post-class, students complete summarization tasks to compare and evaluate different treatment processes. This case study effectively integrates theory with practice, enabling students to gain a comprehensive understanding of improvements and innovations in water treatment technologies.

A municipal wastewater treatment plant upgrade project: As urban development progressed, the effluent quality from the treatment plant failed to meet standards, resulting in eutrophication of surrounding water bodies. The case study details the upgrade plan from Class B to Class A standards, including the installation of denitrification deep bed filters, chemical phosphorus removal systems, optimized aeration systems, and sludge treatment systems. During classroom instruction, students are guided to preview the material through distributed resources and video presentations. In-class, process explanations and skill development are achieved through model demonstrations and scheme analyses. Post-class, in-depth literature review is arranged to help students master the upgrading and optimization of wastewater treatment processes.

2.2.2. Case Study of Emerging Interdisciplinary Fields

Urban Black and Odorous Water Body Ecological Restoration and Landscape Enhancement Project: Urban inland waterways have deteriorated into black and odorous water bodies due to pollution, failing to meet national water environment standards. Comprehensive strategies are urgently required to achieve effective ecological restoration and enhance landscape effects. The case study details specific measures and outcomes in source control, pollution interception, endogenous treatment, ecological restoration, and landscape enhancement. Before class, students analyze water quality conditions through video presentations and key water quality parameters.

During lectures, theoretical explanations and analyses of integrated ecological restoration strategies are delivered, followed by student-led project discussions. Post-class assignments include writing research reports on recent advancements in the field, enabling students to gain a comprehensive understanding and further study of various ecological restoration technologies.

Low-carbon Retrofitting of Wastewater Treatment Plants for Carbon Neutrality: Under the "Dual Carbon" goals, wastewater treatment plants undergo low-carbon upgrades. The case study highlights measures such as optimizing aeration systems, utilizing anaerobic digestion and photovoltaic power generation, and implementing carbon footprint accounting systems. Before class, students are guided to analyze and preview materials. During the session, the course covers carbon emissions from wastewater treatment plants, with a focus on summarizing current cutting-edge research. After class, students participate in field visits and read recommended books and literature to cultivate their environmental awareness and engineering skills.

2.3. Specific Implementation Steps and Classroom Organization of Case Teaching

Leveraging the hierarchical structure of the case library, this course employs a three-phase instructional model: "pre-class preparation, in-class implementation, and post-class extension." Case-based teaching is tailored to three levels—basic, advanced, and extended—through differentiated lesson planning and interactive teacher-student engagement, ensuring precise alignment between learning objectives and students' cognitive capacities. The total course duration is 48 class hours, with case-based instruction accounting for 40% (19.2 hours). The specific allocation and organization are as follows:

2.3.1. Basic Case: Consolidate Theoretical Foundation and Standardize Analytical Logic

The foundational case-based teaching follows a hands-on approach, with each case assigned 2 class hours. Four cases are set up, totaling 8 hours, accounting for 41.7% of the total case-based teaching hours. Each session is divided into two modules: theoretical connection and interactive practice, each allocated 1 hour, ensuring precise alignment between theory and practice.

The pre-class preparation phase is primarily student-driven with teacher guidance as a supplement. Teachers will distribute case study materials through the online teaching platform 3-5 days prior to class, including process principle documents, operational parameter tables, and common issue lists for single sedimentation process optimization cases. Students are required to master core theoretical formulas and operational key points, analyze technical challenges, and develop preliminary solutions. To ensure effective preparation, teachers provide real-time Q&A support in the platform's discussion section. For recurring questions, 5-8 minute supplementary video explanations are created and released to help students overcome cognitive barriers.

The 40-minute lecture adopts a teacher-led, interactive model. During the theoretical review session, instructors use real-world cases to revisit fundamental concepts like sedimentation process types and factors affecting sedimentation efficiency. Through thought-provoking questions such as "Why is the turbidity change in the effluent not significant after adjusting the sedimentation time in this case?", students are guided to connect theory with practical applications, promptly correcting cognitive biases formed during preparatory study. In the subsequent hands-on session, students are divided into 4-5 person groups. Each group receives case-specific process simulation data sheets and must complete parameter optimization calculations and operational procedure mapping within a set timeframe. After group representatives present their findings, instructors provide targeted feedback, focusing on correcting calculation errors and operational logic inconsistencies, thereby standardizing students' engineering analysis approaches.

To reinforce learning outcomes, targeted post-class assignments are designed, including creating optimized process flow diagrams and writing theoretical justifications for parameter adjustments, thereby deepening students' grasp of fundamental concepts. After submission, teachers conduct online group evaluations of selected case studies, forming a complete teaching cycle of "preparation-explanation-practice-feedback" to genuinely enhance the quality of case-based instruction.

2.3.2. Advanced Case Studies: Enhancing Comprehensive Application and Collaborative Skills

Unlike foundational case teaching that emphasizes practical application of basic knowledge, advanced case teaching focuses on enhancing comprehensive knowledge application and cultivating students 'teamwork skills. Its class hour allocation better aligns with the demands of complex engineering tasks. Each advanced case is allocated 3 class hours, featuring two typical cases: waterworks upgrading and sewage treatment plant standardization, totaling 6 class hours (31.3% of the total case teaching hours). The class hours are precisely divided into three phases: "pre-class preparation-in-class discussion-post-class summary," with 0.5 hours for pre-class preparation, 1.5 hours for in-class discussion, and 1 hour for review and summary. This progressive structure ensures students' deep engagement in case analysis.

The pre-class preparation adopts a group-based approach with teacher supervision, aiming to cultivate collaborative awareness through clear task allocation and lay the foundation for integrated knowledge application. One week before class, students are divided into 6-8 person groups, each assigned specific core tasks from the case study. For example, some groups focus on analyzing original process defects, while others compare technical feasibility of different improvement solutions. To ensure preparation quality, teachers provide a 0.5-hour offline guidance session, clearly defining task boundaries, presentation guidelines, and evaluation criteria for each group. Supporting materials such as engineering drawings and cost calculation templates are also provided to help students develop research plans covering process standard references and industry specification reviews. Each group establishes an online collaboration group, with teachers actively joining and regularly monitoring progress. They promptly address issues like data acquisition barriers and uneven task distribution to ensure efficient group collaboration.

The instructional design emphasizes student-centered learning throughout the session, fostering intellectual exchange through collaborative discussions and peer evaluations to enhance comprehensive knowledge application. During the 60-minute group presentations, teams sequentially deliver 10-minute demonstrations using multimedia tools like PPTs, physical models, or 3D animations. These presentations comprehensively present core analysis outcomes including original process limitations, technical modifications, and cost-benefit comparisons. An interactive Q&A session allows cross-group discussions where peers challenge the rationale of proposed solutions—for example, "Why prioritize the ozone-biological activated carbon process over membrane treatment?" —while the presenting team clarifies doubts, deepening case understanding through two-way communication. In the subsequent 40-minute review session, instructors provide precise evaluations across three dimensions: technical feasibility, economic viability, and logical coherence. They systematically organize key concepts such as multi-process integration principles and engineering solution selection methods, supplementing with industry best practices to guide students in developing interdisciplinary approaches for solving complex engineering challenges.

The post-class extension focuses on consolidating achievements and elevating competencies, further solidifying the outcomes of integrated application and collaboration. Teachers require each group to synthesize presentation content and peer review feedback, producing a 3,000-4,000-word case analysis report that incorporates multidimensional considerations of technology, economics, and environmental impact, comprehensively showcasing team collaboration achievements and individual reflections. After submission, teachers select outstanding reports for classroom demonstrations to provide reference examples for all students. Concurrently, they conduct focused discussions on common issues such as incomplete cost analysis and lack of engineering ethics considerations in the reports, continuously refining the teaching loop of "group preparation-collaborative discussion and peer review-evaluation and consolidation." This approach effectively achieves the teaching objectives of enhancing comprehensive application and cultivating collaborative skills.

2.3.3. Extension Layer Case: Tracking Industry Frontiers, Inspiring Innovative Thinking

Building upon foundational practical implementation and advanced collaborative learning, the extension module adopts case-based teaching with dual objectives: tracking industry frontiers and stimulating students' innovative thinking. The curriculum allocates 2.6 class hours per extension case, featuring two cutting-edge projects—ecological restoration of black and odorous water bodies and low-carbon water treatment—totaling 5.2 hours (27% of the case-based teaching load). The instructional framework is structured as: 0.6 hours for frontier analysis, 1.5 hours for presentation and defense, and 0.5 hours for summary and extension, progressively guiding students to engage with industry frontiers and spark innovative ideas.

The pre-class preparation adopts a blended approach of independent research and group collaboration to build a solid foundation for innovative thinking. For two weeks prior to class, students work in 5-6 person groups to conduct independent research on cutting-edge technologies such as smart water management and low-carbon processes. They systematically analyze technical principles, current applications, and development trends by reviewing the latest research literature and industry reports. To prevent overly broad or insufficient research scope, teachers provide targeted materials like technical overviews and expert lecture videos through online platforms, guiding students to focus on key research areas and enhancing both efficiency and quality of their work.

The course centers on interactive sessions, using Q&A to foster innovative thinking and cutting-edge knowledge. During the 24-minute frontier interpretation session, instructors analyze core aspects of advanced technologies through case studies—such as IoT applications in smart water systems for water quality monitoring and carbon footprint methodologies in low-carbon water treatment—while incorporating the latest policy directions from the "dual carbon" goals for the water treatment industry. This builds a solid theoretical and industry foundation for student presentations. The 60-minute Q&A phase features 12-minute presentations by each group, highlighting technological applications, existing challenges, and innovative solutions. The session adopts a "peer review + instructor feedback" model: students evaluate presentations based on innovation and research depth, while instructors highlight strengths and provide optimization suggestions for less effective approaches, guiding students toward rigorous frontier thinking. In the final 20-minute summary session, instructors synthesize interdisciplinary knowledge from case studies, encourage students to explore cutting-edge research areas aligned with their interests, and recommend high-quality academic journals and industry exhibitions to broaden their academic horizons.

The post-class extension program emphasizes implementing innovative tasks to cultivate students 'creative abilities and bridge teaching with research. Teachers assign creative assignments such as designing water quality monitoring solutions for smart water systems and writing analytical essays on low-carbon water treatment technologies, which specifically develop students' practical innovation skills. Outstanding projects will be recommended for university-level innovation and entrepreneurship programs, facilitating the transformation of teaching outcomes into research practices and completing the distinctive " research - defense - innovation - translation" teaching cycle.

3. THE MANIFESTATION OF INNOVATION IN TEACHING REFORM

This educational reform case library balances traditional and cutting-edge content. It not only covers classic water supply and drainage engineering cases to solidify teaching foundations, but also introduces emerging interdisciplinary cases such as smart water management, ecological restoration, and low-carbon water treatment, closely aligning with industry advancements. Structurally, it adopts a tiered optimization approach, dividing cases into foundational, advanced, and extended levels based on their characteristics. This design follows students' cognitive patterns and learning progression, guiding them from basic cases to comprehensive and frontier cases, thereby systematically building knowledge systems and progressively enhancing practical skills. Simultaneously, the library integrates ideological and political education with professional teaching through case-based instruction, embedding ethical considerations throughout the curriculum. It incorporates engineering ethics, sustainable development concepts, and economic awareness, using concrete case analyses to help students strengthen value judgment and responsibility while exploring technical logic, balancing economic costs, assessing ecological impacts, and considering social values. This approach achieves coordinated improvement in comprehensive thinking, professional competence, and ideological and political literacy.

4. PRACTICAL EFFECTS OF TEACHING REFORM

After the implementation of the teaching reform, the learning outcomes of students were analyzed and evaluated, primarily through course assessment results, self-evaluation of engineering practice abilities, and analysis of course participation. The comparative data on the effectiveness of the curriculum reform are shown in the table below:

During classroom discussions and case analyses, students demonstrated high engagement by actively raising questions, thinking critically, and evaluating solutions. Their course submissions clearly show significant improvement in applying knowledge to solve real-world engineering problems. Moreover, students have gained deeper insights into engineering ethics and sustainable development. When analyzing issues and designing projects, they now fully consider environmental and social factors, demonstrating strong engineering literacy.

Table 1 Comparison of Teaching Reform Outcomes

Evaluation metrics	**Before the reform**	**After the reform**	**The growth rate**
Course assessment excellence rate (≥90 points)	10%	21%	+110%
Adoption rate of innovative curriculum design	8%	30%	+275%
Student participation (active speaking frequency per person)	1.2 times	3.8 times	+216.7%
Self-evaluation of engineering practice ability (Full score: 100)	72.5 points	85.2 points	+17.5%
Cognitive achievement rate of engineering ethics (≥80 points)	65%	89%	+36.9%

5. CONCLUSION RESULTS AND DISCUSSION

The case-based teaching reform in “Water Quality Engineering” focuses on core curriculum objectives and new engineering education requirements. By establishing a specialized case library that integrates traditional water supply and drainage engineering with cutting-edge fields like smart water systems, ecological restoration, and low-carbon water treatment, the program optimizes tiered teaching designs aligned with students 'cognitive patterns. It deeply incorporates ideological and political elements, engineering ethics, and sustainable development concepts throughout case selection, analysis, and practical teaching, achieving synergy between ideological guidance and professional instruction. Teaching practices demonstrate significant outcomes: this reform not only enhances students' ability to connect theory with practice, analyze engineering problems, and develop innovative thinking, but also strengthens their engineering ethics, sense of responsibility, and ideological awareness. It helps students embrace the philosophy that "lucid waters and lush mountains are invaluable assets," fostering integrated thinking that balances technological, economic, environmental, and social development. This proves that scientifically implementing case-based teaching is an effective approach to improve Teaching effectiveness and fulfill the fundamental mission of moral education. Moving forward, efforts should focus on enriching the ideological content and cutting-edge features of the case library, continuously exploring teaching models tailored to water supply and drainage engineering, optimizing course evaluation systems, and emphasizing the assessment weight of ideological literacy and practical skills. These measures will solidify the foundation for cultivating applied new engineering talents with professional competitiveness, sense of responsibility, and patriotic commitment.

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CONFLICT STATEMENT

The authors declare no conflict of interest.

COOPERATION STATEMENT

All authors contributed equally to this work and approved the final manuscript.

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