Innovative Reform Design for Inquiry-Based and Interactive Comprehensive Hydraulics Experiment Teaching

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Abstract. This reform addresses critical challenges in the Comprehensive Hydraulics Experiment course, including insufficient student engagement, weak autonomous learning awareness, and inadequate theory-practice integration, through in-depth analysis of core pain points: outdated teaching content misaligned with contemporary advancements, overemphasis on procedural operations at the expense of conceptual understanding, and forced implementation of curriculum-based ideological education. Guided by the "Cultivating Virtue and Pursuing Academic Excellence" philosophy, our student-centered, problem-oriented approach restructures content with authentic case studies, promotes student-designed experimental proposals, deepens analytical discussions, and stimulates intellectual curiosity; innovatively, we establish a collaborative team-based inquiry model integrated with multi-dimensional evaluation to strengthen scientific rigor and teamwork competencies, with practical evidence demonstrating significant improvements in teaching effectiveness and educational outcomes, providing a replicable model for engineering laboratory pedagogy reform.

Keywords: Hydraulics experiment, Inquiry-based learning, Interactive teaching, Pedagogical reform, Curriculum-based ideological and political education, Multi-dimensional evaluation.

1 Introduction

At the Central Conference on Talent-related Work, President Xi Jinping emphasized the imperative to "develop an engineer cultivation system with Chinese characteristics and global competitiveness, building a contingent of engineers loyal to the Party and the country, dedicated and committed, excelling in technological innovation and adept at solving complex engineering problems." To address urgent national strategic demands for high-end engineering talent, the New Excellence Initiative establishes elevated requirements, prompting universities and enterprises across China to implement

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Emerging Engineering Education (3E)-centric innovation models that cultivate outstanding engineers capable of supporting greater self-reliance in high-level science and technology while also advancing high-quality manufacturing development[1–5].

The Hydraulics Comprehensive Experiment serves as a core practical course for Port, Waterway and Coastal Engineering majors, designed to cultivate students' ability to analyze fluid flow phenomena in natural and engineering contexts. Traditional teaching models face critical challenges: passive knowledge reception and mechanical replication hinder deep cognitive engagement; outdated content misaligned with engineering frontiers impedes the translation of abstract theories into practical problem-solving skills; single-dimension assessment fails to objectively evaluate learning processes and collaborative efficacy; forced integration of ideological-political elements undermines educational outcomes. It is imperative to develop an innovative student-centered pedagogy that ignites intrinsic motivation while strengthening competency development and value cultivation.

2 Analysis of Teaching Challenges

Under the traditional experimental teaching model, instruction for courses like fluid flow experiments typically assumes a stereotypical form[6,7]. Generally, teachers, as knowledge transmitters, assume primary responsibility for delivering lectures on experimental principles and demonstrating operational procedures. Within this framework, students often occupy a passive knowledge-receiving role, merely replicating procedures to obtain experimental data and thereby complete lab reports. This pedagogical approach consequently constrains teacher-student communication and peer interaction, thus impeding the formation of a dynamic learning environment.

Hydraulics inherently encompasses intricate laws of fluid motion and mathematical formulas. If these components cannot be presented through vivid and intuitive methods in experimental courses, students may develop apprehension toward the subject, consequently diminishing their learning motivation.

Current course assessment excessively relies on lab reports while neglecting procedural performance in preparatory work, hands-on operations, and collaborative processes. The existing evaluation system fails to adequately account for these process-oriented aspects, resulting in students potentially focusing disproportionately on compiling experimental documentation at the expense of experiential learning during actual experimentation. This ultimately fails to achieve the pedagogical objective of enhancing holistic competencies through laboratory courses.

3 Course Teaching Objectives

3.1 Knowledge Acquisition

Through experimental observation, students examine water flow characteristics under diverse boundary conditions, initial states, and external forces. This approach visually demonstrates complex phenomena during fluid movement, including velocity distribution, pressure variations, vortex generation and evolution, thereby enabling comprehension of the physical laws and mathematical principles embodied within hydrodynamic behavior.

3.2 Competency Development

Through experimental operations, students acquire essential laboratory skills encompassing experimental design planning, control of testing conditions, and troubleshooting during experimental procedures. Furthermore, they gain exposure to modern hydraulic measurement techniques, such as Vectrino, as shown in figure 1, it is a high-precision acoustic Doppler point velocimeter designed to measure the three-dimensional flow velocity of water, it boasts a wide range of applications, primarily deployed in laboratory settings, and can also be used for river channel surveys and oceanographic mapping to capture rapid fluctuations in flow velocity. Thereby broadening their technical perspectives in hydraulic measurement fields and laying foundations for innovative experimental design.

Fig. 1. Vectrino and its application in experiment.

Through experimental training, students develop the capacity to apply fundamental principles of fluid mechanics in conducting in-depth analyses of water movements in rivers and oceans, as well as liquid flows in engineering structures such as pipelines and dams, thereby accurately identifying critical factors governing fluid dynamics. Furthermore, they cultivate preliminary competence in formulating practical solutions to real-world engineering challenges.

3.3 Professional Values

A profound understanding of fluid flow dynamics extends beyond personal academic growth to critically intersect with national strategic priorities such as water resource utilization and water conservancy projects. This recognition enables students to deeply appreciate the significance of their acquired knowledge for national development, thereby fostering a sense of national commitment. Concurrently, the experimental process cultivates a pursuit of precise results and nurtures the spirit of craftsmanship.

Through systematic experimental training, students holistically enhance their professional capabilities, establishing a robust foundation for future scientific research and practical undertakings in related fields.

4 Exploring the Framework Development of Interactive Pedagogical Reform

Guided by the principles of Objective Clarity, Operational Efficiency, Engaging Delivery, Interdisciplinary Extension, and Innovative Thinking, this framework establishes a quadrilateral pedagogical objective system integrating Knowledge, Competency, Engineering Application, and Value Cultivation through deep synthesis.

4.1 Developing Complementary Learning Modules

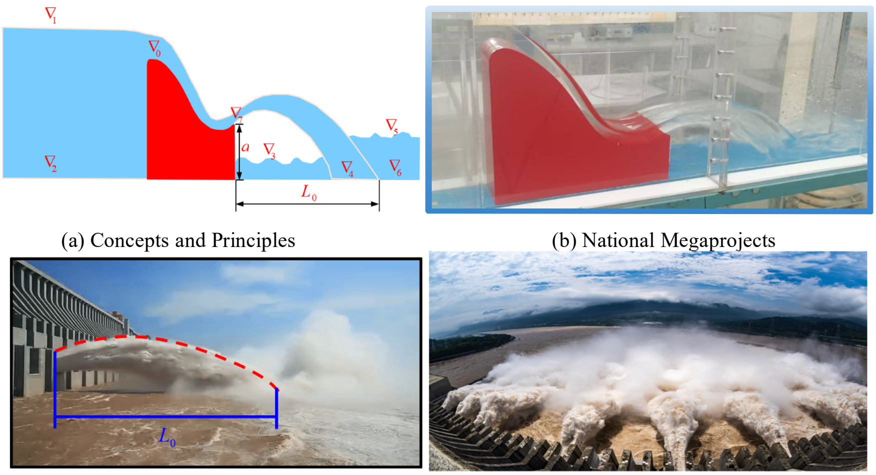
Complementary Learning Modules enrich course content and comprehensively expand students' cognitive frameworks. As Benjamin S. Bloom asserts, "The more adequately students possess prerequisite cognitive conditions for each new learning task, the more actively they engage with the subject matter." Students' existing cognitive structures fundamentally determine the input, comprehension, and assimilation of new knowledge, exerting profound impact on both immediate learning outcomes and long-term academic development[8–10]. This reform initiative leverages the following approaches to fully exploit these complementary modules.

Presenting counterintuitive phenomena from daily life and nature alongside transformative hydraulic innovations that benefit humanity, thereby stimulating students' exploratory drive. This approach guides learners toward proactive and in-depth investigation through on-site verification of these phenomena in laboratory settings. The initiative demonstrates that scientific inquiry is accessible to all, not merely the exclusive domain of scientists. Table 1 summarizes the construction of engaging instructional assets and preparatory modalities. Taking the trajectory bucket energy dissipation experiment as an example, as shown in figure 2, this course first addresses the energy dissipation problem downstream of the Three Gorges Dam to introduce the definition and energy dissipation principle of trajectory bucket energy dissipation. An experiment is arranged to measure its key parameter, the jet trajectory distance. Relevant literature data are then adopted to calculate the actual jet trajectory distance of the Three Gorges Project. By combining the construction history and the vital contributions of the Three Gorges Water Control Project, teachers guide students to understand that the great rejuvenation of the Chinese nation hinges on our own diligent efforts.

Table 1. Construction of engaging instructional assets and preparatory modalities

Serial Number	Engaging Instructional Assets	Fundamental Conceptual Domains	Preparatory Modalities
1	Magnus Effect Trajectory Phenomenon	Bernoulli's Equation	Technical Micro-video

2	Energy Dissolution Challenges at Xiaolangdi Hydropower Station	Orifice Energy Dissipation	Technical Micro-video
3	The Tacoma Narrows Bridge Collapse Enigma	Kármán Vortex Stree	Technical Literature
4	The Magdeburg Hemispheres Experiment	Atmospheric Pressure	Technical Literature
5	Why Water Flows Upward in Siphon Tubes: A Hydraulic Analysis	Energy Conversion	Live Engineering Demonstration
6	The Hydrodynamic Design of Fish Morphology: An Analysis of Rounded Heads and Tapered Tails	Boundary Layer Separation	Visual Documentation
7	Energy Dissolution System at Three Gorges Project	Ski-Jump Energy Dissipation	Technical Micro-video
8	Energy Dissolution System at Gezhouba Project	Hydraulic Jump Energy Dissipation	Technical Micro-video
9	Unveiling the Legend of Dujiangyan	Weir Discharge Coefficient	Technical Micro-video



(a) Concepts and Principles (b) National Megaprojects

(c) Experimental Design (d) Ideological and political education

Fig. 2. Case of Three Gorges project.

Leveraging the Virtual Simulation Center for Waterway Transportation and the Experimental Training Center for Vessel Transportation, this initiative incorporates recent research achievements and competition-winning projects from these facilities. By integrating introductions to cutting-edge disciplinary developments, it broadens students' professional horizons while systematically cultivating their innovative mindset.

Producing micro-videos to demonstrate instrument operational principles, utilization techniques, and procedural protocols, facilitating student preview of experimental knowledge. Integrated with Computer-Aided Instruction (CAI) modules, Figures 3 and 4 show some examples of computer-aided instruction, this is an engineering fluid mechanics virtual simulation software developed by the Hydraulic Laboratory of Zhejiang University. This approach enables pre-class simulation of experimental workflows while incorporating preparatory questions to assess readiness effectiveness.

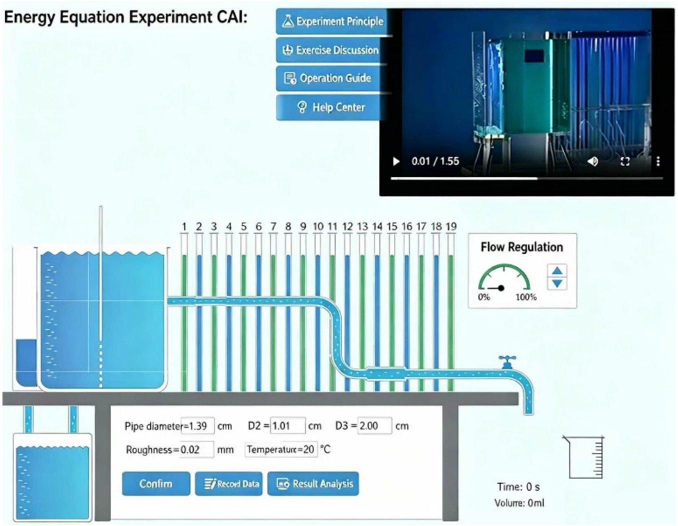


Fig. 3. Example of Energy Equation Experiment.

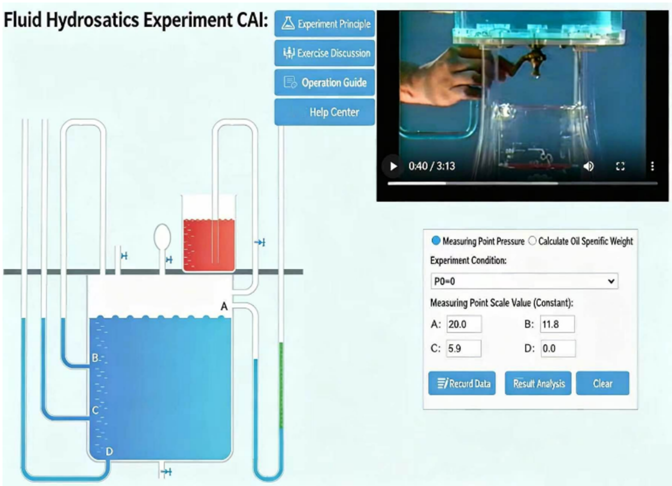


Fig. 4. Example of Hydrostatics Experiment.

4.2 Innovative Pedagogical Framework

This model prioritizes student-centered inquiry-based and interactive methodologies, exploring discipline-specific experimental teaching approaches. It implements an integrated lecture-seminar format that synergistically combines the advantages of large-class instruction and small-group tutorials, thereby enhancing instructional quality and learning efficiency. The framework establishes a multi-tiered, multi-sequence modular curricular architecture centered on learners, systematically developing students' innovative thinking and practical competencies.

The large-class instruction phase is conducted in multimedia classrooms. By integrating modern audiovisual technologies, it reconstructs authentic engineering scenarios while presenting project backgrounds and technical challenges. Experimental principles and objectives are embedded within these contexts to avoid simplistic lecturing, thereby guiding students to comprehend the practical significance of experiments and master the application of experimental methodologies in solving real-world problems. Rather than following conventional knowledge structures, instruction adopts thematic modules featuring specialized hydraulics topics for seminar-style learning. This approach stimulates academic engagement, enhances national identity and patriotic dedication, maintains contemporary relevance, cultivates global perspectives, interconnects knowledge units, and prompts critical reflection. For instance: Open-channel uniform flow concepts are taught through ancient irrigation systems like Zhengguo Canal and modern marvels like Red Flag Canal. Open-channel varied flow and weir flow principles are explored via landmark projects including Dujiangyan, Three Gorges Dam, and the South-North Water Transfer Project. These case studies develop students' ability to identify hydraulic problems in engineering contexts, bridge theoretical-practical divides, and establish professional engineering awareness. Throughout this process, deliberate integration of cutting-edge disciplinary knowledge expands intellectual horizons and nurtures innovative thinking.

The small-group laboratory phase is implemented in experimental facilities. Based on equipment availability and class size, students are organized into specialized experimental units with capped membership. While self-selecting team members and adopting self-assigned names featuring discipline-relevant terminology with positive connotations, students autonomously allocate responsibilities to leverage individual strengths, thereby cultivating collaborative competencies. Inter-unit dynamics establish a constructive competitive experimental environment. Custom-developed data processing software provides immediate feedback on result deviations following basic data input, with error magnitude linked to assessment outcomes. Units exceeding acceptable error thresholds receive one retrial opportunity, systematically instilling a rigorous scientific mindset.

This pedagogical model fully leverages modern university students' proficiency in digital technologies and their preference for personalized learning with instant interaction. By utilizing institutional e-learning platforms and social media applications, we construct a multidimensional interaction framework to enhance student-instructor and peer-to-peer engagement, thereby ensuring real-time instructional responsiveness.

4.3 Refining the Assessment Framework

Through a multidimensional and comprehensive assessment system, this framework promotes teaching refinement and learning enhancement. It implements multi-tiered evaluation throughout the experimental process, encompassing preparatory work, operational procedures, and laboratory reports. The system holistically examines students' comprehension of experimental objectives, procedural planning, theoretical calculations of results, data table design, and analytical problem-solving. By diagnosing preparatory engagement and mastery of instructional goals, instructors dynamically adjust emphasis levels across experimental components. Comprehensive assessment prevents neglect of experimental procedures and report plagiarism. Additionally, collaborative performance metrics evaluate team data quality and in-class participation. The framework incorporates structured peer evaluation through cross-team assessment with anonymous voting to designate Outstanding Experimental Units and intra-team member evaluation to identify Exceptional Contributors. Table 2 provides specific evaluation metrics for the assessment framework.

Table 2. Specific evaluation metrics for the assessment framework

Dimension	Weight	Tier-1 Indicator	Tier-2 Indicator
Individual Process	40%	Pre-lab Preparation (10%)	1.1 Pre-test Accuracy
			1.2 Critical Thinking Depth
		Operational Process (20%)	2.1 Instrument Proficiency
			2.2 Data Acquisition Precision
			2.3 Anomaly Handling
			2.4 Safety Compliance
		Lab Report (10%)	3.1 Objective Elaboration
			3.2 Data Table Standardization
			3.3 Theoretical Calculation
			3.4 Question Innovation
Team Collaboration	30%	Data Quality (15%)	4.1 Experimental Error
		Collaboration Efficacy (15%)	5.1 In-class Contribution
			5.2 Task Allocation
			5.3 Operational Efficiency
Peer Review	30%	Inter-team Evaluation (15%)	6.1 Solution Innovation
			6.2 Instrument Management
			6.3 Workspace Orderliness
			6.4 Discipline Compliance
		Intra-team Evaluation (15%)	7.1 Contribution Matrix

4.4 Refining the Assessment Framework

During instruction on open-channel flow, weir flow, and related topics, this pedagogical approach incorporates case studies of ancient hydraulic engineering marvels, including Dujiangyan, Zhengguo Canal, and Lingqu Canal, alongside modern mega-projects such as the Three Gorges Dam, Gezhouba Dam, and South-North Water Transfer Project. These exemplars highlight China's globally acclaimed achievements in water conservancy infrastructure, cultivating patriotic sentiment, national pride, cultural confidence, and steadfast commitment to the great rejuvenation of the Chinese nation.

Within the water surface profile analysis and computation module, instruction is contextualized within current events to discuss hydraulic engineers' professional responsibilities in flood control, drought relief, urban water management, and aquatic environmental protection. This approach cultivates heightened social accountability. Simultaneously, through introducing professional specifications governing hydraulic structures, including open-channel systems, weirs, and sluice gates—students develop professional regulatory awareness and embrace a legal compliance ethos.

Throughout all instructional phases, multimodal approaches, including classroom presentations, video demonstrations, digital course expansions, and Q&A discussions, systematically introduce hydraulic pioneers and their contributions along the discipline's historical timeline. This methodology guides students to embrace the scientific ethos of revering knowledge, pursuing truth, and embodying unwavering commitment to scientific inquiry through lifelong dedication.

The pedagogical design incorporates Team Spotlight Presentations to enrich classroom engagement. Each specialized unit selects professionally contextualized case studies, including China's landmark hydraulic projects, scientific biographies, pivotal technological innovations, or the historical evolution of hydraulics, as thematic foci. During large-class sessions, student representatives deliver structured expositions, culminating in instructor-led synthesis and contextualization to co-construct comprehensive case narratives.

The teaching reform program has been implemented in the School of Naval Architecture, Ocean and Energy Power Engineering, Wuhan University of Technology. The reform covers two classes majoring in Port, Waterway and Coastal Engineering Design, with a full implementation cycle of three semesters (2021, 2022 and 2023), involving a total of 177 undergraduate students. The practical effectiveness of the reform can be reflected through indicators including students' academic performance before and after the reform, satisfaction evaluation, and satisfaction with ideological and political education. The specific data are shown in Table 3.

Table 3. Reform effectiveness data table

Evaluation Indicators	Pre-reform (Traditional Teaching)	Post-reform (New Teaching Mode)	Improvement Range
Professional course average score (full score=100)	74.2	81.5	+7.3points
Practical skill assessment pass rate	81.1%	92.7%	+11.6%
Student teaching satisfaction score (full score=10)	7.1	9.2	+2.1 points
Student recognition rate of curriculum ideology and politics	68.5%	92.3%	+23.8%

5 Conclusion

To address the inherent drawbacks of the traditional Comprehensive Hydraulics Experiment course, this study developed and implemented an integrated reform framework centered on "inquiry" and "interaction," deeply incorporating ideological-political education and a multidimensional evaluation system. By expanding cognitive horizons through second classroom development, strengthening inquiry via large-small class collaborative teaching, promoting process engagement with innovative multidimensional assessment, and achieving value internalization through seamless ideological integration, the reform effectively resolved critical challenges including insufficient student motivation, theory-practice disconnection, superficial ideological education, and monolithic evaluation methods. This model has demonstrably enhanced students' autonomous learning capacity, engineering practice competence, innovative thinking, teamwork ethos, and social responsibility, empirically validating its effectiveness and transferability while establishing a valuable paradigm for innovating engineering laboratory courses in the new era. This teaching reform and empirical research have an obvious single-institution limitation: all reform practices, data collection and effect verification are completed based on Wuhan University of Technology. Popularization and application in other institutions need targeted adaptive optimization according to their own resource endowments, student characteristics and school-running positioning, so as to form a differentiated and applicable teaching reform scheme.

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