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Teaching reform of hydrogeology and engineering geology for environmental engineering undergraduates under the emerging engineering education initiative

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Abstract: Under the emerging engineering education framework, environmental engineering programs are expected to cultivate graduates with cross-disciplinary perspectives and practical problem-solving capabilities. At the Ocean University of China, the course Hydrogeology and Engineering Geology serves as a core elective within the "Geological Environment" module, bridging earth sciences and engineering applications. However, current instruction remains lecture-dominated, with limited hands-on training, abstract content, low student engagement, and rigid assessment methods. This paper proposes a systematic reform across three dimensions: content selection, teaching methods, and evaluation. Content is streamlined by prioritizing fundamentals and practical topics, adding a 4-hour laboratory component on hydraulic properties, and introducing an artificial intelligence module covering machine learning applications in parameter inversion, water-level forecasting, and hazard assessment. Teaching methods integrate artificial intelligence-driven three-dimensional visualization for conceptual understanding, discussion-based case studies, balanced use of multimedia and blackboard instruction, and comprehensive project-based modules that cover problem identification, experimental design, data collection, theoretical analysis, report writing, and oral defense. Assessment is restructured to a 50:20:30 ratio for final exam, project performance, and continuous evaluation, with open-ended exam questions and peer/self-evaluation components. This reform aims to shift the course from knowledge transmission to competence development, aligning with emerging engineering education goals for applied, innovation-oriented talent.

1. Introduction

The rapid advancement of artificial intelligence (AI), big data, and related technologies is reshaping global industrial structures and demanding a new generation of engineering talent with interdisciplinary vision, innovative thinking, and strong practical skills. In response, China's Ministry of Education has promoted the emerging engineering education (EEE) initiative, which encourages universities to restructure curricula and training models toward future-oriented engineering education (Shen et al., 2020; Dan et al., 2025). The EEE framework emphasizes industry-demand orientation, shifting from discipline-centered to competence-centered education, and stresses cross-disciplinary integration, innovation, and adaptability to complex, evolving engineering challenges (Koh and Zhuang, 2021; Wei and Zhang, 2025).

Ocean University of China's environmental engineering program, leveraging the university's strengths in marine and earth sciences, has developed a distinctive "Environment + Geology + Ocean" interdisciplinary training system. The program was recognized as a provincial first-class undergraduate program in 2019 and a national first-class program in 2020. Its curriculum covers traditional environmental engineering topics while extending into marine environmental protection and geohazard prevention, aligning with national marine strategies and green energy transitions.

Hydrogeology and Engineering Geology is a core elective within this program's geological environment module. The course aims to equip students with the ability to analyze engineering-induced geological changes and propose appropriate countermeasures. However, current teaching relies heavily on textbook knowledge transmission, with insufficient practical training and limited student engagement. Abstract concepts, lack of prerequisite knowledge, and constrained class hours (32 total) further hinder effective learning. This paper analyzes these challenges and proposes

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concrete reforms to align the course with EEE competence-oriented goals.

2. Course characteristics

The course uses Fundamentals of Hydrogeology (Zhang et al., 2011) and Principles of Engineering Geological Analysis (Zhang et al., 2016) as textbooks. Hydrogeology covers groundwater distribution, occurrence, flow laws, recharge-discharge mechanisms, and chemical evolution. Engineering geology addresses active faults, earthquakes, sand liquefaction, land subsidence, slope stability, karst, seepage deformation, and coastal erosion. Students are expected to master basic concepts, systematically analyze groundwater-related hazards, write professsional reports on common engineering geological problems, and develop awareness of hazard prevention and environmental protection.

Three notable features characterize the course.

(1) Strong interdisciplinary nature. Content draws from mathematics, hydraulics, soil mechanics, seepage mechanics, geology, surveying, physical geography, and earth sciences. These knowledge areas are tightly interlinked, demanding solid foundational preparation.

(2) Large content volume. Hydrogeology covers water distribution, rock voids, groundwater occurrence, flow regimes, recharge-discharge, chemical composition, and environmental interactions. Engineering geology addresses faults, earthquakes, liquefaction, subsidence, slope stability, karst, and seepage. Given the 32-hour limit, the material far exceeds available instructional time. Students often lack prior exposure to hydraulics, soil mechanics, or geology, increasing comprehension difficulty.

(3) Strong practical orientation. The course trains students to analyze hazard formation conditions, influencing factors, evolution patterns, and engineering responses, and to write evidence-based professional reports. Typical scenarios include dewatering-induced subsidence near river-crossing excavations, seepage stability of reservoir slopes, and groundwater over-exploitation impact assessments. Students integrate borehole data, pumping tests, permeability coefficients, specific yield, drawdown calculations, and consolidation parameters to estimate subsidence and propose mitigation measures, bridging site-scale and regional-scale analyses.

3. Current teaching problems

(1) Mismatch between textbook content and class hours. Both textbooks are written for geology majors and assume more instructional time. With only 32 hours available, while geology programs typically allocate 32+ hours to either hydrogeology or engineering geology alone, the content cannot be covered adequately.

(2) Abstract content and teacher-centered delivery. Groundwater flow theory, subsidence mechanisms, and slope stability analysis involve numerous abstract concepts and mathematical formulations. Instruction relies on PowerPoint and blackboard lectures, with little interactive time. The condensed schedule forces rapid pacing, leaving insufficient room for in-class assimilation and practice.

(3) Weak practical training. No laboratory sessions or field trips are arranged. Practical exposure is limited to images, video clips, and schematic diagrams shown in class. Students never operate instruments, collect field data, or conduct experiments, resulting in superficial understanding and poor engineering intuition.

(4) Insufficient prerequisite knowledge and low motivation. Students enter with general science backgrounds but lack systematic prior knowledge of watershed concepts, mineral and rock identification, or geological processes. Abstract groundwater theory and mechanical analysis appear obscure, reducing interest and self-directed learning.

(5) Limited AI integration. The curriculum does not introduce AI applications in hydrogeology and engineering geology. Teaching tools remain conventional, with no data-driven modeling or intelligent analysis components, leaving students unprepared for industry digitalization trends.

(6) Rigid assessment system. Grades consist of a final closed-book exam (60%) and continuous assessment (40%), the latter based mainly on attendance and homework. Classroom interaction, project work, and higher-order analytical skills are inadequately captured.

4. Proposed reforms

4.1 Content optimization

To resolve the time-content conflict, content selection follows the principle of "streamlined fundamentals, practical emphasis, and systemic coherence" aligned with environmental engineering program objectives. The teaching content and corresponding class hours before and after optimization are presented in Table 1. Take hydrogeology for example, core topics including distribution and circulation of water on earth, voids and water in rocks and soils, occurrence of groundwater, fundamental laws of groundwater flow, chemical composition and evolution of groundwater, recharge and discharge of groundwater receive prioritized classroom instruction. Simpler or less major-relevant content such as water in the unsaturated zone, groundwater flow systems, groundwater regime and balance, etc. is assigned for self-study. This "intensive teaching plus guided self-study" strategy preserves overall structure while concentrating in-class time on theory directly relevant to subsequent courses and engineering practice.

In view of the role that laboratory instruction plays in bolstering experiential learning (Gleeson et al., 2012), an extra 4-hour laboratory session is now included, focusing on hydraulic property measurements including porosity, specific yield, specific retention, water-holding capacity, and permeability coefficient tests. Recognizing that teamwork is a critical employability skill and learning outcome in the geosciences (Nyarko and Petcovic, 2022), this work designed the lab to proceed through three phases: concept review, individual practice, and collaborative group work. Students first recall definitions and interrelations of parameters, then perform experiments following standard protocols. Instructors minimize intervention, instead guiding observation and data recording. Groups compare results and discuss sources

Table 1 Comparison of the teaching content and corresponding class hours before and after optimization for the Hydrogeology and Engineering Geology course.

Content		Classroom teaching, Hours	
		Before optimization	After optimization
Hydrogeology	Introduction	Y, 1	Y, 1
	Distribution and circulation of water on earth	Y, 1	Y, 2
	Voids and water in rocks and soils	Y, 1	Y, 2
	Occurrence of groundwater	Y, 1	Y, 2
	Fundamental laws of groundwater flow	Y, 1	Y, 2
	Water in the unsaturated zone	Y, 1	N, SS
	Chemical composition and evolution of groundwater	Y, 1	Y, 2
	Recharge and discharge of groundwater	Y, 1	Y, 2
	Groundwater flow systems	Y, 1	N, SS
	Groundwater regime and balance	Y, 1	N, SS
	Pore water	Y, 1	N, SS
	Fracture water	Y, 1	N, SS
	Karst water	Y, 1	N, SS
	Groundwater resources and management	Y, 1	N, SS
	Groundwater and the environment	Y, 1	Y, 1
	Trends and methodology in modern hydrogeology	Y, 1	N, SS
	Laboratory session A	N, 0	Y, 2
Engineering Geology	Geological analysis of structural features of crustal rock masses	Y, 1	Y, 1
	Natural stress state of crustal rock masses	Y, 1	Y, 1
	Deformation and failure of rock masses	Y, 1	N, SS
	Geological study of active faults	Y, 1	Y, 1
	Geological study of earthquakes	Y, 1	Y, 1
	Geological analysis of reservoir-induced seismicity	Y, 1	N, SS
	Regional sand liquefaction induced by earthquakes	Y, 2	Y, 2
	Geological analysis of land subsidence and ground fissures	Y, 1	Y, 2
	Geological analysis of slope stability	Y, 2	Y, 2
	Geological analysis of surrounding rock stability	Y, 1	N, SS
	Geological analysis of foundation rock mass stability	Y, 1	N, SS
	Geological analysis of karst and karst leakage	Y, 1	Y, SS
	Geological analysis of seepage deformation	Y, 2	Y, SS
	Laboratory session B	N, 0	Y, SS

Note: SS denotes self-study.

variation such as soil structure differences, operational errors, and reading deviations. Through this "hands-on, observe, compare, attribute" process, students directly verify Darcy's law and build deeper understanding of parameter interconnections. Group work also fosters peer learning and teamwork.

Given the growing importance and widespread application of AI in hydrogeology and engineering geology research (Zhou et al., 2026; Zounemat-Kermani and Kheimi, 2026), an AI module is introduced, covering machine learning and deep learning applications in hydrogeological parameter inversion, groundwater-level forecasting, and geohazard susceptibility mapping. Case studies illustrate data-driven methodologies. Topics include intelligent remote sensing interpretation, AI-assisted groundwater monitoring, and early warning systems. Practical training in data preprocessing, feature engineering, and model development equips students to use AI tools in complex geological problem-solving. This module shifts the course from pure knowledge transfer toward "intelligent competence" development.

4.2 Diversified teaching methods

(1) AI-driven 3D visualization. Visualization facilitates students' understanding of abstract knowledge

points, thereby enhancing the overall learning experience (Aguiar, 2023; Li and Davis, 2022). For abstract processes such as groundwater seepage, contaminant transport, and soil deformation, numerical simulation and visualization tools render dynamic 3D representations. Making “invisible groundwater” visible and “complex mechanics” intuitive reduces cognitive load and increases instructional appeal.

(2) Discussion-based learning. Each session begins with guiding questions linked to new content, following a “perceptual to rational, concrete to abstract” trajectory. For example, when teaching “rock voids and water”, students judge whether everyday items such as sponges, ceramic pots, and sand filters qualify as porous media, then progress to water occurrence and stress states. When discussing groundwater-environment interactions, cases such as fluorosis-endemic areas (water chemistry), scale formation (hardness), and urban subsidence (over-pumping) are analyzed. Teachers facilitate, question, and synthesize, training students in problem identification, logical reasoning, and oral articulation.

(3) Balanced multimedia and blackboard use. Multimedia efficiently presents rich information but must avoid passive “screen-reading”. Instructors control pacing and pause at critical points. For logically sequential content such as flow-net construction, blackboard demonstration is preferred. The instructor progressively draws boundary conditions, derives equipotential and flow lines, and applies orthogonality rules, showing the complete reasoning chain. This combination presents results and frameworks via multimedia while revealing methodologies via blackboard, training systematic thinking from boundary conditions to engineering judgments.

(4) Comprehensive project-based modules. Early in the semester, several topics are designed based on available laboratory equipment (e.g., permeameters, oedometer, direct shear apparatus) and common geohazards (e.g., subsidence, seepage failure, slope instability). Each project addresses a relatively complete engineering problem, covering experimental design, data acquisition, theoretical computation, analysis, and countermeasure proposals. For example, the topic “Subsidence assessment due to dewatering near a river-crossing excavation” requires students to design permeability tests, determine consolidation parameters, calculate excavation inflow, estimate drawdown radius, and compute total subsidence (Xu et al., 2017). Students work in groups of 3-5, selecting topics, independently designing protocols, dividing operations, collecting and processing data, performing calculations, and submitting written reports followed by 10-20-minute presentations and Q&A sessions. Presentations must articulate problem analysis, experimental design, key computational steps, and engineering recommendations. This sequence targets multiple competences: planning (design), teamwork (collaboration), hands-on skills (execution), analytical calculation (data and theory), technical writing (reporting), and oral communication (presentation and defense). The whole chain from problem identification to engineering recommendations systematically builds comprehensive problem-solving ability.

4.3 Assessment system restructuring

A process-oriented and comprehensive evaluation framework (Xu et al., 2023; Yang, 2024) is adopted to redirect student effort from final-exam cramming to sustained learning and skill development. The grade composition is: final exam (50%), comprehensive project (20%), and continuous assessment (30%). Project grades cover design quality, operational correctness, data completeness, computational accuracy, report quality, and presentation and defense performance. Continuous assessment comprises attendance (40%), homework and lab reports (30%), and classroom interaction and group discussion participation (30%), covering “attendance, comprehension, output” dimensions.

The final exam includes open-ended questions requiring integrated application of knowledge to real geological scenarios, rather than rote recall of definitions and formulas. For example, students may be given groundwater-level monitoring data and stratigraphic profiles, then asked to infer trends, analyze potential causes, and propose engineering responses, differentiating those who can translate knowledge into judgment. For project presentations and lab performance, peer and self-evaluation are incorporated alongside instructor scoring, enhancing objectivity and fostering reflective learning. This multi-dimensional approach ensures assessment truly reflects students’ knowledge, practical skills, collaboration, and innovation, creating a positive “assessment-driven learning” cycle.

5. Conclusion

Hydrogeology and Engineering Geology is a core course within the environmental engineering curriculum, playing an irreplaceable role in developing students’ ability to identify engineering geological problems, systematically analyze hydrogeological hazards, and perform quantitative calculations. However, the course currently suffers from a severe mismatch between extensive interdisciplinary content and constrained class hours. Traditional lecture-based instruction, weak practical training, inadequate prerequisite knowledge, low student engagement, absence of AI integration, and rigid assessment undermine its effectiveness in cultivating EEE-aligned talent.

This paper proposes systematic reforms across content, pedagogy, and evaluation. Content is streamlined to prioritize core topics, supplemented by a laboratory component on hydraulic properties and an AI module covering machine learning applications in parameter inversion, water-level forecasting, and hazard assessment, shifting the course toward “intelligent competence" development. Teaching methods employ AI-driven 3D visualization to reduce conceptual abstraction, discussion-based case studies for logical reasoning, balanced multimedia and blackboard instruction for systematic thinking, and comprehensive project-based modules covering the full chain from design to defense. Assessment is restructured to a 50:20:30 ratio (final exam, project, continuous evaluation), with open-ended exam questions and peer and self-evaluation mechanisms.

Successful implementation requires supporting resources including lab manuals, project guidelines, and scoring rubrics. Pilot testing in 1-2 classes with pre- and post-comparisons, satisfaction surveys, and peer review will allow iterative adjustments. Through this systemic teaching reconstruction, the course is expected to effectively bridge geological theory and engineering practice, providing solid support for cultivating high-quality, application-oriented environmental engineering graduates under the EEE framework.

Conflicts of interest

The authors declare no competing interest.

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