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AI-Empowered Teaching Reform Based on OBE Philosophy: An Exploration of the "Petroleum and Natural Gas Geology" Course for the Resource Exploration Engineering Major

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Abstract: In response to the urgent demand for composite geological talents capable of "intelligent interpretation, data-driven analysis, and engineering decision-making" driven by the digital transformation of the energy industry, the traditional "Petroleum and Natural Gas Geology" course faces challenges such as lagging content, singular evaluation methods, and a lack of engineering context. Based on the Outcome-Based Education (OBE) philosophy, this study proposes and implements a teaching reform model characterized as "OBE-Led and AI-Empowered." First, applying the principle of Backward Design, a course objective system covering knowledge, skills, engineering capabilities, and comprehensive qualities was constructed, clarifying the core requirement of "solving complex petroleum geological problems." Second, the course content was reconstructed into a "Geological Intelligent Cognitive Pyramid" (Fundamentals Layer - Methods Layer - Application Layer), deeply integrating AI technologies with hydrocarbon accumulation theories. Third, an intelligent teaching mode driven by "Complex Basin Problems" was designed, utilizing an AI toolchain (e.g., intelligent logging interpretation, fault identification, migration simulation) to support Project-Based Learning (PBL) and case studies, thereby realizing full-process data-driven evaluation. Practice indicates that this model effectively bridges the gap between education and industry, significantly enhancing students' abilities in multi-source data fusion analysis and engineering decision-making. It provides a reference pathway for constructing a new teaching paradigm for the Resource Exploration Engineering major in the intelligent era.

1. Introduction

Industry Transformation and New Talent Demands: With the deep adjustment of the global energy structure and the rapid advancement of unconventional oil and gas exploration, the petroleum industry is accelerating its transition toward digitalization and intelligence. The widespread application of technologies - such as intelligent well logging, deep learning processing of seismic data, and numerical simulation of hydrocarbon accumulation - marks a comprehensive shift in exploration models from "experience-driven" to "data-driven" and "intelligent decision-oriented." This transformation has reshaped the capability profile of geological talents: practitioners must not only possess a solid foundation in geological theory but also master the ability to fuse and analyze multi-source heterogeneous data (logging, seismic, core, and geochemical data). They must be proficient in using AI tools for lithology identification and facies classification, and be capable of conducting quantitative characterization of hydrocarbon enrichment laws based on big data. Consequently, there is an urgent industrial demand for composite geological talents capable of "intelligent interpretation, data-driven analysis, and engineering decision-making."

Course Status and Teaching Pain Points: "Petroleum and Natural Gas Geology" serves as a core backbone course for the Resource Exploration Engineering major, bearing the critical task of constructing the theoretical framework of hydrocarbon "generation-migration-accumulation" and cultivating exploration engineering thinking. The course aims to foster students' ability to solve complex engineering problems, such as identifying migration pathways, reconstructing accumulation periods, and designing exploration schemes. However, facing rapid industry iteration, the current teaching mode exhibits significant lags: First, content updates are slow, failing to cover frontier intelligent technologies; Second, teaching methods are singular, lacking dynamic interpretation training based on big data and visual scenarios; Third, the evaluation system is limited, failing to precisely measure students' higher-order engineering thinking. Existing sporadic attempts at AI teaching often remain at the level of tool demonstration, lacking systematic integration with course objectives and evaluation systems, thus failing to truly support the transformation of the talent training model.

Theoretical Basis and Technical Pathway: Addressing these pain points, introducing the Outcome-Based Education (OBE) philosophy serves as the logical starting point for reform. OBE emphasizes reconstructing teaching through "Backward Design" clarifying the core capability of "solving complex engineering problems" that students should possess upon graduation[1]. This facilitates a leap in course objectives from mere "knowledge mastery" to "comprehensive interpretation, intelligent judgment, and engineering decision-making," directly benchmarking against the Washington Accord and industry competencies[2-3]. Meanwhile, the massive volume and multi-source heterogeneous nature of geoscience data provide fertile ground for AI application. Currently, AI empowers teaching through four pathways: scenario reproduction (VR/AR), intelligent interpretation (Machine Learning), generative assistance (LLM), and data-driven evaluation toolchains[4-6]. However, facing the potential weakening of geological thinking caused by the algorithm "black box" and challenges regarding data ethics, teaching reform must be a paradigm reconstruction grounded in the steadfast cultivation of geological thinking[7].

Research Objective: Under the new situation, constructing an integrated teaching mode of "OBE-led and AI-empowered" is an inevitable choice for the reform of this course[8]. This study aims to use the OBE philosophy as the core to clarify the knowledge, skills, and engineering qualities the course should cultivate; and to use AI technology as the lever to achieve the visualization of teaching content, the intelligentization of learning paths, and the digitalization of evaluation mechanisms. By systematically reconstructing course objectives, knowledge systems, teaching modes, and evaluation mechanisms, this research seeks to bridge the gap between traditional teaching and industry demands, exploring a new pathway for training Resource Exploration Engineering talents that maintains the rigor of geological theory while matching the requirements of the intelligent era.

2. Course Design: OBE-Based Course Objectives and Competency Structure

2.1. Overall Course Objectives

Guided by the Outcome-Based Education (OBE) philosophy, the formulation of course objectives aligns closely with the educational positioning of Shandong Institute of Petroleum and Chemical Technology (SDIPCT): Based in Shandong, Serving the Industry, Emphasizing Application, and Strengthening Engineering.

Adhering to the principle of "Backward Design", the course team conducted in-depth surveys on the latest demands for geological talents in the energy resources sector. Starting from "the positions graduates should be competent for (e.g., oil and gas exploration, reservoir evaluation, digital oilfield construction)", the required engineering analysis and practical capabilities were derived. Consequently, an objective system integrating "Knowledge, Skills, Engineering Capabilities, and Comprehensive Qualities" was constructed, aiming to cultivate composite applied talents who possess "Geological Proficiency, Data Literacy, Interpretation Capability, and Decision-Making Skills".

The specific objectives are detailed as follows:

(1) Knowledge Objectives: The course requires students to systematically master core theories of sedimentology, structural geology, reservoir geology, and basin analysis. Students must deeply comprehend the geological laws of hydrocarbon "generation, migration, accumulation, and preservation", and establish a theoretical framework for interpreting logging, seismic, and geochemical data, laying a solid cognitive foundation for solving complex geological problems.

(2) Skill Objectives: The focus is on cultivating abilities in acquiring, processing, and visualizing multi-source geological data. Students should possess basic skills to comprehensively analyze well logging curves, seismic sections, cores, and mud logging information. Particularly in the context of intelligence, students are required to proficiently apply AI-assisted tools for automated lithology identification, reservoir parameter prediction, and intelligent trap analysis to adapt to the industry's digital transformation.

(3) Engineering Capabilities: The course emphasizes the ability to identify, model, and solve "complex petroleum geological problems". Students should be capable of conducting accumulation pattern analysis, resource estimation, and exploration deployment based on geological conditions and engineering constraints. They must demonstrate the ability to propose technical schemes and conduct feasibility demonstrations in authentic engineering scenarios, reflecting the "Engineering-Oriented" cultivation characteristic.

(4) Comprehensive Qualities: The course reinforces geological thinking, innovative consciousness, data ethics, and teamwork spirit. It aims to cultivate students' ability to assume professional roles within interdisciplinary teams, enabling them to complete the full task chain from data cleaning and model building to result reporting, while possessing lifelong learning awareness and professional responsibility.

In summary, under the guidance of the OBE philosophy, the objective system of this course not only reflects the systematic nature of basic geological knowledge but also emphasizes the construction of a competency structure based on engineering scenarios. This ensures that upon graduation, students possess the core competencies of "Geological Proficiency, Data Literacy, Interpretation Capability, and Decision-Making Skills", providing the energy exploration and development sector with composite applied talents equipped with both intelligent literacy and practical capabilities.

2.2. Course Learning Outcomes (LOs)

To support the aforementioned overall objectives, the course refines capability requirements into five quantifiable and assessable Course Learning Outcomes (LOs) and clarifies their support relationship with the Graduation Requirements (GRs) (see Table 1).

Table 1: Course Learning Outcomes.

ID	Course Learning Outcomes (LOs)	Competency Category (OBE Dimensions)	Supported Graduation Requirements (Examples)
LO1	Theoretical Construction Capability: Systematically master core theories of sedimentology, structural geology, reservoir geology, and petroleum geology; deeply understand the fundamental laws and controlling factors of hydrocarbon generation-migration-accumulation-preservation.	Knowledge	Graduation Requirement 1 (Engineering Knowledge): Apply knowledge of mathematics, natural science, engineering fundamentals, and specialization to solve complex engineering problems.
LO2	Multi-Source Data Analysis Capability: Able to acquire and comprehensively interpret multi-source geological data (including well logging, seismic, core, and geochemical data) and select appropriate tools to extract key geological information.	Skills	Graduation Requirement 2 (Problem Analysis): Identify, formulate, and analyze complex engineering problems using principles of mathematics, natural science, and engineering science.
LO3	Intelligent Tool Application Capability: Able to apply AI technologies (e.g., machine learning classification, image recognition) to conduct lithology identification, facies classification, and reservoir prediction; understand the applicability and limitations of algorithms in geological applications.	Digital & AI Literacy	Graduation Requirement 5 (Use of Modern Tools): Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools.
LO4	Engineering Decision-Making & Scheme Design: Able to conduct accumulation unit zonation and system modeling in complex geological contexts; integrate multi-source evidence to propose rational exploration deployment suggestions and resource evaluation schemes.	Engineering Capability	Graduation Requirement 4 (Investigation/Design): Able to propose, analyze, and solve complex engineering problems in the field of resource exploration.
LO5	Comprehensive Professionalism: Possess strong geological thinking, professional ethics, and teamwork skills; able to write professional reports and communicate effectively regarding complex geological problems.	Soft Skills & Professionalism	Graduation Requirement 9 (Communication & Individual/Team Work): Possess professional qualities such as communication, teamwork, and lifelong learning awareness.

The LO1–LO5 system fully embodies the "Backward Design" philosophy of OBE:

Alignment with Positioning: It aligns with the talent cultivation positioning of Shandong Institute of Petroleum and Chemical Technology (SDIPCT)-"Application-oriented, Engineering-led, and Serving the Energy Industry".

Industry-Driven Derivation: Capabilities are distilled from industry positions (e.g., oil and gas exploration, reservoir evaluation, digital oilfield, intelligent interpretation) and professional accreditation requirements.

Structured Competency: Course outcomes are refined into four categories -Knowledge, Skills, Engineering Capabilities, and Comprehensive Qualities - forming a complete, capability-oriented curriculum structure.

3. AI-Empowered Reconstruction of the Course Content System

Based on the OBE philosophy, this study strictly aligns with the course objectives (M1-M3) in the syllabus of "Petroleum and Natural Gas Geology". Addressing the disconnect between traditional content and the demands of the intelligent era, we constructed a three-layered course content system: the "Geological Intelligent Cognitive Pyramid" (Fundamentals Layer - Methods Layer - Application Layer). This system aims to achieve progressive cultivation from "Geological Principle Cognition" to "Intelligent Method Application" and finally to "Comprehensive Engineering Decision-Making", ensuring deep consistency among teaching content, practical training, and capability outputs.

3.1. Geological Fundamentals Layer

Orientation and Goal: As the base of the pyramid, this layer corresponds to the core theories of hydrocarbon "generation, migration, accumulation, and preservation" (Chapters 1-7). It directly supports Course Objective M1, aiming to cultivate students' cognitive ability to translate geological phenomena into "data features".

Reconstruction Strategy:

Logical Structuralization: Transforming traditional fragmented lectures into a system organized by the logical chain of "Concept-Model-Mechanism". This involves systematically restructuring content related to hydrocarbon accumulation elements, sedimentary system architectures, and structural control factors, thereby reinforcing students' grasp of geological causal logic.

Adding a "Data Cognition" Module: To adapt to intelligent working modes, we introduce the teaching of multi-source data features (logging, mud logging, seismic, and geochemical data) synchronously when explaining geological entities such as source rocks, reservoirs, and traps. By establishing the mapping relationship of "Geological Entity - Geophysical Response - Data Feature", we help students bridge the gap between pure "Geological Phenomenon Cognition" and a "Bidirectional Understanding of Data and Geology", laying a data cognitive foundation for subsequent Geo-AI training.

3.2. Geo-AI Methods Layer

Orientation and Goal: Located in the middle of the pyramid, the Methods Layer corresponds to professional skill training in reservoir evaluation, migration analysis, trap measurement, and resource assessment (Chapters 3-6 and experiments). This layer supports Course Objectives M2 and M3, focusing on cultivating students' ability to use modern technical tools to solve complex geological problems.

Reconstruction Strategy:

Constructing a "Dual-Track" Fusion System: On the basis of consolidating traditional geological analysis methods (e.g., well logging interpretation, trap identification), we systematically introduce AI intelligent interpretation methods. For instance, Machine Learning classification algorithms are introduced in lithology identification and sedimentary facies analysis, while Deep Learning models are applied in fault identification and seismic facies analysis.

Emphasizing "Three-Element Coupling": The teaching focus is not on algorithm programming, but on the coupled application of "Geological Mechanism - Data Features - AI Methods". Students are required to understand the applicability boundaries, data requirements, and interpretation logic of different AI models in geological analysis. This elevates them from mere "tool users" to analysts capable of synergizing "Geological Logic and Intelligent Algorithms" to solve complex geological problems that are difficult to address with a single method.

3.3. Geo-Engineering Application Layer

Orientation and Goal: The top of the pyramid targets authentic oil and gas exploration engineering scenarios, corresponding to higher-order content such as comprehensive reservoir analysis, exploration program design, and resource evaluation (Chapters 8-9). This layer fully supports M1-M3, aiming to cultivate students' engineering decision-making capabilities, innovative thinking, and interdisciplinary collaboration literacy.

Reconstruction Strategy:

Full-Chain Task Design: Relying on Project-Based Learning (PBL) and virtual simulation platforms, we design comprehensive tasks such as "Basin Modelling", "Accumulation System Construction" and "Exploration Target Optimization".

Closed-Loop Decision Training: We construct a complete workflow of "Engineering Problem - Data Analysis - Geological Modelling - Intelligent Prediction - Engineering Decision". Students are guided to comprehensively apply theories from the Fundamentals Layer and tools from the Methods Layer to perform logical deductions amidst conflicting multi-source evidence, completing the entire process from reconstruction of accumulation periods and analysis of hydrocarbon enrichment laws to the formulation of exploration deployment schemes.

Internalization of Literacy: In practical drills, the assessment focuses on the student's ability to demonstrate the feasibility of technical schemes and evaluate geological risks, achieving the ultimate transformation from "Knowledge and Skills" to "Engineering Competency".

4. AI-Driven Teaching Mode Design

In the AI-empowered curriculum reform, this course adopts the teaching philosophy of "Complex Basin Problem-Driven Learning" to construct an intelligent teaching mode based on authentic engineering scenarios. Taking the "Hydrocarbon Migration Characteristics of the Bohai Bay Rift Basin" as a typical task scenario, the course integrates Project-Based Learning (PBL), Case-Based Learning (CBL), and AI Intelligent Analysis Platforms. This approach guides students to achieve knowledge construction, method acquisition, and engineering capability development within real geological problems[9-10].

The teaching activities commence with the formulation of engineering problems, such as "How does multi-stage tectonic activity in the Bohai Bay Rift Basin affect hydrocarbon migration pathways?" and "Do faults act as barriers or conduits for hydrocarbon accumulation?". Students are guided to construct preliminary geological models based on sedimentary, structural, geochemical, and seismic data. During this process, AI models are leveraged to conduct automatic fault identification, prediction of Source-Reservoir-Cap assemblages, and simulation of migration pathways. This enables students to extract valid evidence from massive datasets and form comprehensive interpretations constrained by multi-source data.

The instructional design emphasizes a chain-like learning logic of "Geological Mechanism - Data Features - AI Methods - Engineering Judgment". Working in teams, students are required to complete model building, parameter selection, interpretation of migration simulation results, and exploration deployment recommendations. They utilize visualization tools to generate result reports, achieving outcome-oriented engineering expression. This mode effectively reinforces students' abilities to identify problems, invoke AI tools, synthesize evidence, demonstrate schemes, and make engineering decisions within complex basin contexts. Consequently, it shifts the course from traditional knowledge instruction to a deep learning mode of "Intelligent Empowerment + Engineering Orientation", which aligns more closely with the energy industry's demand for intelligent geological talents (Figure 1).

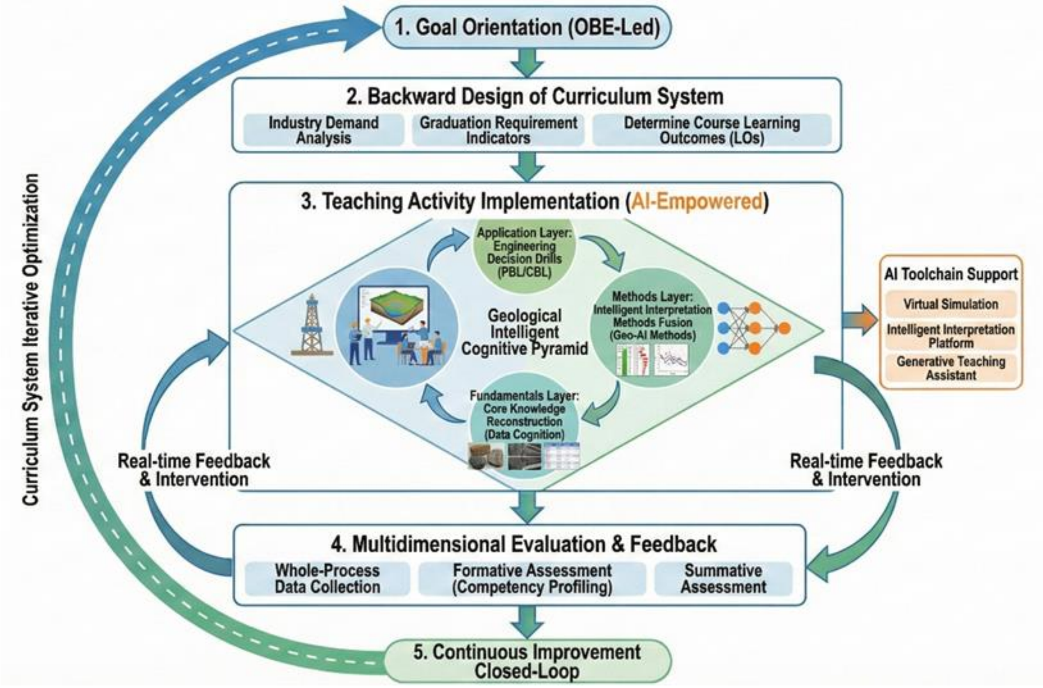

Figure 1: AI-Empowered Teaching Model Flowchart Based on OBE Philosophy.

5. Discussion and Outlook

5.1. Reform Effectiveness: Teaching Gains and Capability Reshaping

The practice of AI-empowered teaching reform based on the OBE philosophy in "Petroleum and Natural Gas Geology" demonstrates that the deep integration of intelligent technology and Outcome-Based Education significantly enhances teaching quality. First, relying on whole-process data analysis and competency profiling, AI enables the precise implementation of "Measurable Learning Outcomes" and "Continuous Improvement" emphasized by OBE, supporting a personalized, adaptive "Student-Centered" teaching mode. Second, the embedding of AI intelligent interpretation tools and high-fidelity engineering scenarios not only enhances the authenticity and openness of teaching but also accelerates the formation of a composite capability structure of "Geological Cognition + Data Thinking + Intelligent Tools". This achieves a deep alignment between talent cultivation and the intelligent transformation of the energy industry.

5.2. Realistic Challenges: Tension among Resources, Thinking, and Ethics

However, the deep integration of AI and OBE still faces multiple challenges:

(1) Resource Bottlenecks: The construction of high-quality multi-source data and computing power in some universities lags behind.

(2) Thinking Risks: Over-reliance on AI "Black Box" tools may weaken students' understanding of geological genetic mechanisms, leading to a degradation of engineering judgment. This presents a potential conflict with the OBE goal of cultivating the "ability to solve complex problems".

(3) Adaptability Issues: Challenges include data ethics and privacy risks, as well as the contradiction between "Rapid Technology Iteration" and "Relatively Stable Teaching Systems", which places higher demands on teachers' interdisciplinary capabilities and instructional design.

5.3. Future Outlook: Deepening Pathways for Paradigm Transformation

Looking ahead, the reform needs to be deepened across four dimensions:

(1) Strengthen the construction of data resources and teaching platforms to consolidate the digital foundation.

(2) Adhere to the principle of "Geology-Based, AI-Assisted", constructing an Explainable AI (XAI) teaching framework to ensure that tool application serves the cultivation of disciplinary thinking.

(3) Establish sound educational data governance and ethical norms.

(4) Build a dynamic synergistic mechanism of "OBE Competency Framework - AI Tool Iteration - Teaching Content Update".

In summary, the AI-OBE integration model will continue to drive the paradigm shift of the course from "Knowledge Transmission" to "Intelligent Empowerment + Data-Driven + Engineering Decision-Making", providing a solid pathway for talent training in the era of intelligent exploration.

6. Conclusions

Focusing on the teaching reform of "Petroleum and Natural Gas Geology," a core course for the Resource Exploration Engineering major, this study constructs an integrated teaching system defined by "OBE-led Objectives and AI-empowered Processes". The main conclusions are as follows:

(1) By introducing the OBE philosophy into geological education and establishing a competency indicator system benchmarking against industry competencies through Backward Design, the course objectives have successfully transitioned from mere "knowledge transmission" to a "competency-based" orientation.

(2) The constructed "Geological Intelligent Cognitive Pyramid" system realizes a progressive logical closed loop from "Geological Principles" to "Intelligent Methods" and finally to "Engineering Decision-Making", resolving the disconnect between traditional textbook content and frontier intelligent technologies.

(3) The PBL teaching mode based on AI toolchains enables students to achieve a deep integration of geological thinking and data thinking within authentic engineering scenarios (such as the Bohai Bay Basin), significantly strengthening their ability to solve complex engineering problems.

(4) Although the reform has shown significant results, future efforts must guard against students' "Black Box" reliance on AI tools. It is essential to adhere to the principle of "Geological Logic as the Foundation, Intelligent Technology as the Assistance", and to promote the sustainable development of the teaching paradigm by continuously optimizing educational data governance and curriculum iteration mechanisms.

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