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In-depth Exploration of AI-empowered Teaching Reform in "Crystallography and Mineralogy" Course: A Case Study of Shandong Institute of Petroleum and Chemical Technology

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Abstract: With the rapid development of artificial intelligence technology, the education sector is undergoing profound transformation. As a foundational course for geology, materials science, and other disciplines, traditional teaching models of "Crystallography and Mineralogy" face limitations in visual teaching, practical ability cultivation, and personalized learning. Taking Shandong Institute of Petroleum and Chemical Technology as an example, this paper explores the application pathways of AI technology in the teaching reform of the "Crystallography and Mineralogy" course. By analyzing the current teaching status and combining the characteristics of AI technology, specific strategies are proposed from four dimensions: optimization of teaching content, innovation of teaching methods, construction of practical systems, and reform of evaluation models. The aim is to build a new teaching model integrating "AI+Education", enhance students' theoretical cognition, practical ability, and innovative thinking, and provide reference for cultivating high-quality professionals to meet the needs of the intelligent era.

1. Introduction

Crystallography and Mineralogy is a discipline that studies crystal structures, mineral compositions, and identification methods. Characterized by strong theoretical abstraction and high practical operational requirements, traditional teaching relies on blackboard drawing, observation of physical specimens, and laboratory analysis, with issues such as insufficient visualization, limited specimen resources, and low student engagement[1]. With the development of AI technologies (such as machine learning, virtual simulation, and image recognition), their advantages in data processing, 3D modeling, and intelligent diagnosis have provided new possibilities for curriculum teaching reform. Currently, the teaching of the "Crystallography and Mineralogy" course faces three challenges: first, the difficulty in integrating teaching content with the technological application needs of the AI era; second, the limitation of practical teaching by physical specimens and equipment, making it difficult for students to access complex mineral cases; third, the evaluation system focusing on knowledge memorization while neglecting the cultivation of higher-order thinking skills. Therefore, exploring AI-empowered teaching reform paths has become an inevitable choice to improve course quality and cultivate innovative talents[2].

2. Basic Course Content

"Crystallography and Mineralogy" is a compulsory foundational professional course offered to students majoring in Resource Exploration Engineering, featuring strong theoretical and practical characteristics. The textbook we use is Crystallography and Mineralogy (4th Edition), co-authored by Shanrong Zhao[3]. The course consists of 56 class hours, including 40 class hours of lecture courses and 16 class hours of laboratory sessions. Through this course, students will master the crystallographic and crystal chemical knowledge inherent in minerals, as well as the physical and chemical knowledge related to mineral properties, genesis, and applications. Closely integrated with supporting laboratory courses, the curriculum aims to enable students to identify and characterize common minerals.

3. AI-empowered Teaching Reform Strategies

3.1 Optimizing Teaching Content and Integrating AI Technology with Interdisciplinary Knowledge

The course content should be updated by incorporating AI technologies. For instance, when explaining crystal structures, machine learning algorithms for the automatic classification of crystal symmetry should be introduced; in mineral identification chapters, image recognition technologies (such as the application of convolutional neural networks in mineral micrograph recognition) should be integrated; and when introducing mineral genesis, cases of AI-simulated mineral crystallization processes under different geological conditions should be incorporated.

Knowledge from computer science (e.g., Python programming fundamentals), data science (mineral big data analysis), and geology (mineral genesis and distribution) should be integrated. An optional module on "AI-based Mineral Data Analysis" should be offered to cultivate students' ability to solve complex problems using intelligent tools.

3.2 Innovating Teaching Methods to Create Intelligent Interactive Classrooms

The 3D crystal structure virtual simulation system should be developed to enable students to observe crystal growth processes and rotate crystal models for symmetry analysis via AR devices. AI technologies should be employed to generate high-resolution image libraries of mineral hand specimens and thin sections, supporting interactive operations such as zooming, annotation, and feature comparison to overcome the limitations of physical specimens.

An AI teaching assistant system should be established to automatically generate personalized learning pathways based on students' in-class response data and experimental operation records: crystal structure animation tutorials should be delivered to students with weak spatial imagination, and targeted case training should be provided to students with high error rates in mineral identification.

Projects including "Development of AI Mineral Identification Systems" and "Machine Learning-Based Prediction of Mineral Genesis" should be designed to guide students to complete data collection (e.g., photographing campus mineral specimens), model training (using open-source AI frameworks), and result presentation in groups, thereby fostering teamwork and innovation capabilities.

3.3 Reconstructing Practical Teaching Systems and Expanding Intelligent Practice Scenarios

An AI-driven virtual experiment platform should be developed to simulate X-ray diffraction experiments (generating diffraction patterns and enabling intelligent analysis via parameter input), mineral hardness testing (acquiring data through virtual tool operations), and observation of crystal optical properties (automatically calculating parameters such as refractive index), thereby reducing equipment costs and ensuring safety.

Global typical mineral specimen data (including composition, structure, and occurrence) should be integrated to construct a database with AI retrieval functions. Students upload mineral photos or composition data, and the system automatically matches similar minerals and provides identification basis, supplementing the shortage of physical specimen resources.

Real mineral exploration data (e.g., drilling core mineral analysis reports) should be introduced through collaboration with geological exploration enterprises. Students should be guided to use AI tools (such as clustering algorithms) to analyze mineral assemblage characteristics, predict reservoir distribution, and enhance engineering practice capabilities.

3.4 Improving Evaluation Systems and Implementing Intelligent Process-Oriented Assessment

An evaluation model of "Knowledge + Skills + Innovation" should be constructed: at the knowledge level, automatic correction of objective questions should be realized through AI question banks; at the skills level, a virtual experiment operation scoring system (e.g., accuracy of crystal structure drawing and standardization of mineral identification procedures) should be adopted; at the innovation level, assessments should be conducted through project defense and AI-assisted feasibility analysis of proposals.

AI should be utilized to analyze students' behavioral data in virtual experiments and online discussions (such as frequency of incorrect operations and quality of questions), generate learning diagnosis reports, and enable teachers to adjust teaching strategies accordingly, thereby achieving the integration of teaching, learning, and assessment.

4. Course teaching reform content

Shandong University of Petroleum and Chemical Technology’s exploration of AI-assisted teaching in the "Crystallography and Mineralogy" course is still in its initial stage. Although preliminary attempts at technology integration have been made, significant weaknesses remain in the depth of tool application, personalized support, and data-driven optimization. An analysis should be conducted based on the teaching data from the second semester of the 2024–2025 academic year (involving Class 3 and Class 4 of the 2024 cohort), focusing on three aspects: existing problems, preliminary exploration, and reform direction.

4.1 Weaknesses and Specific Manifestations of AI-Assisted Teaching

Single-function tools: Currently, only basic online testing systems (e.g., automatic correction of chapter quizzes) have been introduced, without core AI technologies such as 3D visualization and virtual simulation. For instance, in the experimental scores of Classes 3 and 4, the pass rate for "polarizing microscope operation" questions was only 70%, and some students scored below 50 points in experimental operations due to the lack of virtual hands-on training. Insufficient resource coverage: The mineral specimen library contains only over 200 common minerals, with a lack of complex mineral cases.

"One-size-fits-all" teaching model: The online learning platform fails to implement differentiated content delivery, leading to polarized online learning scores in Class 3 (highest score: 96.43, lowest score: 2.175), with 6 students scoring below 60 points. Delayed identification of weak points: Reliance on manual analysis of score data prevents real-time capture of students' cognitive blind spots via AI. For example, the pass rate for abstract concept questions on "optical indicatrix section judgment" was only 60%.

Single evaluation system: Process-oriented assessment still relies primarily on "online tests (10%) + experimental reports (30%)," excluding AI-analyzed learning behavior data, resulting in a discrimination index of only 0.28.

Shortage of hardware equipment: The university lacks laboratories equipped with VR devices, resulting in students averaging less than 2 hours of virtual experiment duration per semester. This hardware deficiency prevents teachers from independently designing AI teaching cases, leading to a lower achievement rate (75%) for course objective M3 (polarizing microscope operation) compared to M1 (85%) and M2 (80%).

4.2 Targeted Reform Directions and Preliminary Explorations

To address the above issues, the following optimization measures have been initiated:

The researchers developed a "3D Interactive Crystal Structure System," with the first batch featuring dynamic models of 20 typical minerals (e.g., quartz, feldspar), enabling students to freely rotate and observe crystal face symbols. The system introduces an AI mineral identification API, which connects to a global mineral database (containing over 100,000 samples) and supports automatic matching of composition and genesis via uploaded microscopic photos.

The platform generates "learning diagnosis reports" based on learning behaviour data (e.g., online test errors, experimental operation trajectories) and pushes a "crystal symmetry basic supplementary package" to all students. An intelligent Q&A robot is developed to answer high-frequency questions such as "extinction phenomenon" and "cleavage angle measurement" in real time, reducing the response time to within 10 seconds.

An "AI process evaluation" module (accounting for 20%) is added, which uses NLP to analyze the logical coherence of experimental reports and automatically identifies issues like "non-standard descriptions" and "contradictory conclusions." A "dynamic difficulty adjustment mechanism" is introduced to automatically adapt question difficulty based on class average scores, aiming to increase the discrimination index to above 0.35.

"AI Teaching Workshops" are organized, where enterprise technicians are invited to train teachers in skills such as virtual simulation platform construction and machine learning model application. Provincial teaching reform project funds are applied for to plan the addition of 2 sets of VR equipment and 5 high-performance graphics workstations, ensuring that the average virtual experiment duration per student increases to 5 hours per semester.

4.3 Phased Results and Reflections

4.3.1 Strengthening Faculty Development

The technical literacy and practical guidance capabilities of faculty represent the core bottleneck limiting the advancement of AI-assisted teaching. Currently, 80% of instructors only possess basic office software proficiency, preventing independent development of teaching cases such as "3D crystal modeling" and "AI mineral identification." This deficiency has resulted in the achievement rate of course objective M3 (polarizing microscope operation) (75%) significantly lagging behind M1 (85%) and M2 (80%). To address this, a "AI + Major" dual-track training framework is proposed: (1) Implement specialized workshops on "virtual simulation tool development" and "educational data mining," mandating faculty certification in Python fundamentals and AI teaching platform operations within one year; (2) Arrange faculty secondments to oilfield enterprises for participation in "mineral exploration AI modeling" projects, transforming real-world industry cases (e.g., "machine learning-driven reservoir mineral prediction") into instructional content to enhance theoretical-practical integration capabilities.

4.3.2 Improving Practical Teaching Resources

Insufficient practical resources directly impede the development of students' operational skills. The university's lack of VR laboratories results in students averaging less than 2 hours of virtual experiments per semester, with Classes 3 and 4 scoring average experimental grades of 77.93 and 79.78—falling short of the target score of 85. Additionally, the physical specimen library only covers over 200 common minerals, failing to meet demands for complex experiments such as "mineral genesis analysis." Three resource optimization strategies are proposed: (1) Allocate special funds to procure additional VR equipment and high-performance graphics workstations, ensuring virtual experiment duration increases to 5 hours per student per semester; (2) Collaborate with enterprises to establish an "AI Mineral Resource Library," integrating expanded mineral micrographs and exploration datasets to enable automatic matching of composition and genesis via student-uploaded specimen images; (3) Partner with oilfield enterprises to develop off-campus internship bases, hosting students in hands-on projects like "mineral thin-section identification" and "reservoir analysis" to address gaps in on-campus resources.

4.3.3 Optimizing the Evaluation System

The existing evaluation system exhibits issues such as "overemphasis on outcomes over process" and "insufficient discrimination." While formative assessment accounts for 40% of the total score (online learning + chapter tests + experiments) and final exams 60%, process-oriented evaluation lacks integration of AI-analyzed learning behavior data (e.g., response time, error patterns), resulting in a total score discrimination index of only 0.28173 and 9.52% of students scoring below 59. A "three-dimensional evaluation framework" is recommended: (1) Increase formative assessment weight to 50%, introducing AI-analyzed dimensions like "experimental operation standardization" and "logical coherence of project reports" (e.g., using NLP technology to identify "data contradictions" and "one-sided conclusions" in reports); (2) Optimize exam parameters by raising comprehensive application questions from 20% to 30%, designing integrated questions combining "theory + experiment + case analysis" (e.g., "inferring rock genesis from AI mineral identification results"); (3) Establish "personal growth portfolios" to track students' ability trajectories from "online learning errors" to "final comprehensive application," providing a basis for personalized guidance.

4.3.4 Promoting Sustained Deepening of Teaching Reform

Disconnection between teaching content and industry needs has led to insufficient knowledge transfer capabilities among students. In course objective M1, the score rate for comprehensive application questions such as "factors affecting isomorphism" is only 65%, while in M2, the score rate for "mineral genesis analysis" questions is less than 70%, reflecting inadequate integration of "AI + Geology" cutting-edge content into teaching. Reform should be deepened in two aspects: (1) Dynamically adjust curriculum content by adding modules like "Application of Machine Learning in Mineral Classification" and "Case Studies on AI Reservoir Prediction," transforming industry new technologies (e.g., exploration big data platforms) into teaching cases; (2) Establish a "teaching-research-industry" collaborative mechanism, encouraging teachers to convert research projects (e.g., "Study on Shale Mineral Assemblages") into student practical topics.

5. Conclusion

AI technology provides an innovative pathway for the teaching reform of the "Crystallography and Mineralogy" course. Shandong University of Petroleum and Chemical Technology has initially established an "AI + Education" integration model by optimizing teaching content, innovating teaching methods, reconstructing practical systems, and improving evaluation mechanisms. Despite existing limitations in the depth of technological application, personalized support, and faculty/hardware infrastructure, phased results have been achieved in enhancing students' learning interest and practical abilities through measures such as developing 3D interactive resource libraries, piloting AI tutor guidance, and optimizing data-driven evaluation. Moving forward, it is necessary to further deepen interdisciplinary content integration, strengthen faculty technical literacy, and improve university-enterprise collaboration mechanisms. This will promote the upgrading of AI empowerment from tool application to teaching model reconstruction, providing a sustainable reform paradigm for cultivating high-quality geological professionals in the intelligent era.

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