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Research on the Practice and Effect of Ai Enabling Geological Engineering Teaching—Taking the Course of Principles of Engineering Geological Analysis as an Example

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Abstract

By analyzing data from the International Energy Agency (IEA) and combining open data released by the International Monetary Fund (IMF) and the Ministry of Natural Resources of China, this paper systematically examines the development pattern of the global mineral industry from four core dimensions: world economy, mineral exploration and development, supply-demand dynamics, and regulatory policies. It draws the following conclusions: the global mineral industry is currently confronted with prominent challenges. As the world's largest producer of 30 out of the 43 critical raw materials listed by the European Union and the sole import source of 8 out of the 35 critical minerals for the United States, China has long been at the forefront of international strategic competition. Coupled with the IMF's forecast of a mere 2.7% global economic growth rate in 2030 and the escalating risks in geopolitics as well as environmental, social and governance (ESG), the development of the global mineral industry is severely constrained. Meanwhile, mineral resource science has achieved three major transformations: in research content, it has shifted from describing regional resource and environmental characteristics to focusing on global environmental changes and human well-being; in research themes, it has moved beyond traditional pattern research to research on the coupling of patterns and processes, extending to issues related to sustainable development; and in research methodologies, it has tended to be integrated, systematic and quantitative. This multi-dimensional integrated development trend provides crucial scientific and technological support for achieving the global goals of carbon peaking and carbon neutrality and addressing climate change.

Keywords

Mineral resources; Minerals Market; Carbon peaking; Carbon neutrality; Policy recommendations; Global climate change.

1. Introduction

1.1. Global Trend of AI-Enabled Education Transformation

The rapid development of artificial intelligence (AI) has triggered a paradigm shift in global education. The integration of AI with education has become a strategic priority for many countries, as it is regarded as a core driver for improving educational quality, promoting educational equity, and realizing sustainable development (UNESCO, 2022). For example, the European Union's "Digital Education Action Plan (2021–2027)" emphasizes the need to strengthen the application of AI in teaching, learning, and evaluation to build a digital education

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ecosystem (European Commission, 2021). The United States has launched the "National AI R&D Strategic Plan" and "AI for Education" initiative, investing heavily in the development of AI teaching tools, intelligent tutoring systems, and educational data analytics platforms (White House, 2023). In Asia, Japan's "Society 5.0" strategy and South Korea's "AI Education Vision 2030" both prioritize the integration of AI into the entire education chain, from basic education to higher education (MEXT, 2022; Ministry of Education, Republic of Korea, 2021).

In China, the integration of AI and education has been elevated to a national strategy. The Outline of the Plan for Building an Education Power (2024–2035), jointly issued by the Central Committee of the Communist Party of China and the State Council, clearly states that "we should accelerate the digital transformation of education, promote the deep integration of AI, big data, and other technologies with education and teaching, and build a high-quality education system" (Central Government of China, 2024). The Opinions on Accelerating Educational Digitalization, released by the Ministry of Education and eight other departments, The Ministry of Education of China (2024) further specifies the key tasks of AI integration in education, which include developing thematic large language models for disciplinary education, building intelligent teaching platforms, and establishing data-driven teaching evaluation mechanisms. These policies provide a strong institutional guarantee for the innovation and practice of AI-enabled education in Chinese universities.

1.2. Characteristics and Challenges of Geological Engineering Education

Geological engineering is a highly interdisciplinary and practice-oriented discipline that integrates geology, engineering mechanics, environmental science, and computer technology. It plays a crucial role in national key projects such as geological exploration, mineral resource development, infrastructure construction, and geological disaster prevention and mitigation (Chen et al., 2023; Li et al., 2022). The primary objective of geological engineering education is to develop professionals who are adept at applying scientific and engineering principles to geological challenges, equipped with modern skills, and committed to serving the public interest through ethical practices. with solid theoretical knowledge, strong practical skills, and innovative thinking; they are capable of solving complex engineering problems in real-world scenarios. However, traditional geological engineering education is confronted with several intractable challenges:

Abstraction of Theoretical Knowledge: Geological engineering encompasses numerous abstract concepts, including deep geological structures, stratigraphic evolution, and rock mechanics principles. Traditional teaching methods (e.g., blackboard writing, 2D slides, and lectures) fail to visualize these complex concepts, leading to students' difficulty in constructing spatial cognitive models and poor understanding of key knowledge points (Wang et al., 2021). For example, when explaining the formation mechanism of folds and faults, 2D diagrams can only show cross-sectional views, making it difficult for students to grasp the 3D spatial distribution and evolutionary process of geological structures.

Limitations of Practical Teaching: Practical training is an essential part of geological engineering education, including field geological surveys, indoor geotechnical experiments, and engineering design projects. However, traditional practical teaching is constrained by multiple factors: (1) Fieldwork is limited by geographical conditions, weather, and safety risks, resulting in students' lack of exposure to diverse geological environments (e.g., karst landforms, mountainous areas, coastal zones) (Zhang et al., 2020); (2) Experimental equipment is outdated and insufficient—many universities still use experimental instruments purchased more than 10 years ago, with a renewal rate of less than 30%, which cannot meet the needs of modern geological engineering practice (Liu et al., 2022); (3) The student-teacher ratio in practical teaching is unbalanced—each teacher is responsible for guiding 25–30 students on average,

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leading to inadequate individual guidance and low efficiency of practical training (Zhao et al., 2023).

Deficiencies in Traditional Evaluation Systems: The traditional curriculum evaluation of geological engineering mainly relies on final exams and homework scores, with a single evaluation dimension and excessive emphasis on theoretical knowledge (Chen & Li, 2020). This evaluation method cannot comprehensively reflect students' practical skills, innovative abilities, and learning processes, and it is difficult to provide targeted feedback for teaching improvement. For example, in the evaluation of fieldwork, teachers often give scores based on students' internship reports, ignoring the actual operation process and problem-solving abilities, resulting in a disconnect between evaluation results and practical performance.

Lag in Teaching Content and Industry Demand: With the rapid development of geological engineering technology (e.g., UAV geological mapping, remote sensing interpretation, big data analysis for geological disasters), the knowledge and skills required by the industry are constantly updated. However, traditional teaching content is outdated, with less than 20% of frontier technologies integrated into the curriculum, leading to a gap between graduates' capabilities and industry needs (Huang et al., 2023). A survey shows that more than 60% of geological engineering enterprises believe that new graduates lack the ability to use modern geological equipment and software, and need 1–2 years of on-the-job training to meet the job requirements (China Geological Survey, 2022).

1.3. Policy Support for Educational Reform in Guizhou Province

In response to national strategies, Guizhou Province has issued a series of policies to promote the digital transformation of education. The Implementation Plan for Establishing a High-Quality and Balanced Basic Public Education Service System in Guizhou Province (2024–2027) proposes to "strengthen the construction of educational informatization infrastructure, build smart campuses, and explore AI-enabled personalized teaching models" (People's Government of Guizhou Province, 2024). Guizhou Institute of Technology, as a key local university focusing on engineering and technology, has taken the lead in launching the "AI + Geological Engineering" pilot teaching reform in 2024, aiming to solve the traditional teaching problems and cultivate high-quality technical talents adapting to the digital era.

2. Literature Review

2.1. Curriculum Reform in Geological Engineering

2.1.1 Characteristics and Requirements of Geological Engineering Education

Geological engineering is an interdisciplinary discipline that combines basic geological theory with engineering practice, focusing on solving engineering problems related to geological environments (Ding et al., 2022). According to the Criteria for Accrediting Engineering Programs (ABET, 2023), geological engineering graduates should possess the following core competencies: (1) mastery of basic knowledge in geology, mechanics, mathematics, and physics; (2) ability to design and conduct geological surveys, experiments, and data analysis; (3) ability to identify, analyze, and solve complex geological engineering problems; (4) proficiency in using modern engineering tools and software; (5) awareness of sustainable development and social responsibility.

To meet these requirements, geological engineering education must balance theoretical teaching and practical training, and integrate frontier technologies and industry needs into the curriculum (Liu et al., 2021). However, traditional geological engineering education has several drawbacks, as summarized in Table 1.

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Table 1. Limitations of Traditional Geological Engineering Education

Aspect	Specific Limitations	References
Theoretical Teaching	Abstract concepts, 2D teaching methods, poor spatial visualization	Wang et al., 2021
Practical Training	Limited fieldwork opportunities, outdated equipment, inadequate individual guidance	Zhang et al., 2020
Curriculum Content	Outdated knowledge, low proportion of frontier technologies, disconnection with industry	Huang et al., 2023
Teaching Methods	Teacher-centered, passive learning, lack of interaction and collaboration	Chen & Li, 2020
Evaluation System	Single-dimensional indicators, emphasis on results over processes, strong subjectivity	Zhao et al., 2023

2.1.2 International Research on Geological Engineering Curriculum Reform

Foreign universities have a long history of geological engineering education and have carried out a series of reform practices to address the limitations of traditional teaching.

United States: MIT's Department of Earth, Atmospheric, and Planetary Sciences launched the "Geological Engineering 2.0" program, integrating AI, big data, and remote sensing technology into the curriculum (MIT, 2022). The program emphasizes project-based learning (PBL), where students participate in real-world projects such as geological hazard assessment and environmental remediation, and use AI tools to analyze geological data. Stanford University developed a virtual fieldwork platform using VR technology, allowing students to simulate geological surveys in diverse environments (e.g., deserts, oceans, polar regions) without geographical restrictions (Stanford University, 2023).

United Kingdom: Imperial College London revised its geological engineering curriculum to increase the proportion of practical courses from 30% to 50%, including fieldwork in Scotland, Wales, and other regions, and introduced industry mentors to guide students' project design (Imperial College London, 2022). The University of Edinburgh developed a blended teaching model combining online courses and offline workshops, using AI to analyze students' learning data and provide personalized learning recommendations (University of Edinburgh, 2024).

Australia: The University of Melbourne's School of Earth Sciences collaborated with mining companies such as BHP Billiton to develop a "Industry-University Integration" curriculum, integrating corporate projects and technical training into the teaching process (University of Melbourne, 2023). Students participate in on-site internships at mining sites and use AI-based geological exploration software to process and analyze real mining data.

These international reforms share several common characteristics: (1) emphasis on the integration of technology and teaching, especially the application of AI, VR, and big data; (2) strengthening of industry-university collaboration to narrow the gap between education and practice; (3) adoption of student-centered teaching methods such as PBL and blended learning; (4) improvement of the evaluation system to include process-oriented and competency-based indicators.

2.1.3 Domestic Research on Geological Engineering Curriculum Reform

In China, universities have also carried out various reform initiatives in geological engineering education in recent years, focusing on teaching philosophy, model, content, and evaluation.

Teaching Philosophy Innovation: Tongji University, Chengdu University of Technology, and China University of Geosciences (Wuhan) proposed the concept of "Integration of Science and Education, Emphasizing Two Fundamentals and Strengthening Two Competencies" (Chen et al., 2021). This concept integrates national key laboratories and research projects into teaching,

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allowing students to participate in scientific research at an early stage and promoting the transformation of research achievements into teaching resources. For example, research on landslide prediction and prevention has been integrated into the course Geological Disaster Prevention and Control, enhancing students' ability to solve complex engineering problems.

Teaching Model Reform: Chengdu University of Technology adopted a "three-tiered practical teaching model" (basic, comprehensive, innovative) and developed 194 practical projects (including 78 virtual projects) (Li et al., 2022). The university also implemented a flipped classroom model for core courses, where students learn theoretical knowledge online independently and participate in discussions, experiments, and project design offline. Evaluation results show that this model increased students' classroom participation rate from 35% to 72% and improved their practical ability by 40%.

Curriculum System Optimization: Chongqing University optimized the geological engineering curriculum system by integrating overlapping courses and establishing specialized course clusters (e.g., Geological Exploration, Geotechnical Engineering, Environmental Geology) (Wang et al., 2023). The university also increased the proportion of interdisciplinary courses, such as AI for Geological Data Analysis and Remote Sensing Technology in Geology, to enhance students' digital literacy.

Evaluation System Improvement: China University of Mining and Technology (Beijing) established a multi-dimensional evaluation system combining process evaluation and result evaluation, including indicators such as classroom participation, homework completion, project design, and fieldwork performance (Zhang et al., 2021). The university used online platforms to collect real-time learning data and adopted a combination of teacher evaluation, peer evaluation, and self-evaluation to improve the objectivity of evaluation.

Despite these achievements, domestic research on geological engineering curriculum reform still has some shortcomings: (1) the application of AI technology is mostly limited to auxiliary tools (e.g., online courses, homework correction) and lacks in-depth integration with core teaching links (e.g., practical training, project design); (2) the evaluation index system is not comprehensive enough, with insufficient attention to students' innovative abilities and digital skills; (3) there is a lack of long-term tracking studies to verify the sustainability of reform effects.

2.2. AI-Enabled Teaching Reform: Theoretical Basis and Research Status

2.2.1. Theoretical Basis of AI-Enabled Education

AI-enabled education is based on multiple theories, including constructivism, personalized learning theory, and data-driven decision-making theory.

Constructivism: Proposed by Piaget and Vygotsky, constructivism emphasizes that learning is an active process of knowledge construction rather than passive acceptance of information (Piaget, 1972). AI technology supports constructivist learning by providing personalized learning resources, interactive learning environments, and collaborative learning tools. For example, virtual simulation platforms allow students to construct knowledge through hands-on operation and exploration, while intelligent tutoring systems provide targeted guidance based on students' learning progress and cognitive characteristics.

Personalized Learning Theory: Personalized learning advocates that teaching should adapt to individual differences in students' learning styles, interests, and abilities (Gardner, 1983). AI achieves personalized learning by analyzing multi-source data (e.g., learning behavior, test scores, interaction records) to identify students' strengths and weaknesses, and then generating personalized learning paths and resource recommendations. Machine learning algorithms such as collaborative filtering and content-based filtering are widely used in personalized learning systems (Baker & Inventado, 2014).

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Data-Driven Decision-Making Theory: Data-driven decision-making emphasizes using data analysis to guide teaching practice and policy formulation (Mandinach & Gummer, 2016). In AI-enabled education, teaching data (e.g., student learning behavior, teacher teaching process, learning outcomes) are collected, processed, and analyzed to evaluate teaching effects, identify problems, and optimize teaching strategies. This theory provides a methodological basis for the construction of the curriculum evaluation index system in this study.

In addition, several technology acceptance models have been used to study the adoption of AI in education, such as the Technology Acceptance Model (TAM) (Davis, 1989), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003), and the Extended TAM Model (Teo et al., 2019). These models identify key factors influencing the acceptance of AI teaching tools by teachers and students, such as perceived usefulness, perceived ease of use, social influence, and facilitating conditions, providing a theoretical framework for the promotion of AI-enabled reform.

2.2.2. International Research on AI-Enabled Teaching Reform

Foreign research on AI-enabled teaching reform has a relatively mature theoretical system and rich practical cases, covering basic education, higher education, and vocational education.

AI Teaching Tools and Platforms: Magic School AI (USA) has developed more than 150 AI teaching tools covering curriculum design, learning assessment, and classroom interaction (Magic School AI, 2024). The platform uses natural language processing (NLP) and machine learning to generate personalized lesson plans, automatic grading of assignments, and intelligent feedback. A case study in Colorado's Aurora School District showed that the platform reduced teachers' workload by 40% and improved students' academic performance by 15% (Smith et al., 2023).

Intelligent Tutoring Systems (ITS): Carnegie Learning's ITS for mathematics uses adaptive learning algorithms to adjust the difficulty and pace of learning according to students' performance (Carnegie Learning, 2022). The system provides real-time feedback and guidance, helping students master difficult concepts. A randomized controlled trial with 5,000 middle school students found that the ITS improved students' math scores by 22% compared with traditional teaching (Koedinger et al., 2021).

Virtual Simulation and VR/AR Technology: zSpace (USA) developed a VR-based science teaching platform that allows students to interact with 3D models of atoms, cells, and geological structures (zSpace, 2023). A study at Stanford University showed that using the platform improved students' spatial reasoning ability by 35% and enhanced their interest in science by 60% (Johnson et al., 2022).

Ethical and Social Issues: With the widespread application of AI in education, ethical issues such as data privacy, algorithm bias, and educational equity have attracted increasing attention. The British Ministry of Education's report "Generative AI in Education" emphasizes that AI tools should be developed with the participation of educators to avoid replacing teacher-student interaction (Department for Education, UK, 2024). The Digital Promise organization in the United States proposed a "Digital Equity Framework" to address the gap in access to AI tools between different regions and groups (Digital Promise, 2023).

2.2.3. Domestic Research on AI-Enabled Teaching Reform

Domestic research on AI-enabled teaching reform has developed rapidly in recent years, driven by national policies and technological progress, with a focus on higher education and engineering education.

Policy-Driven Development: The Chinese government has issued a series of policies to promote AI-enabled education, such as the "New Engineering" initiative and the "AI + Education" Action Plan. These policies encourage universities to develop AI-related courses, build intelligent

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teaching platforms, and train teachers' AI application abilities (Ministry of Education of China, 2023).

Technology Application in Engineering Education: Tianjin University developed an AI-enabled virtual simulation platform for mechanical engineering, integrating 3D modeling, finite element analysis, and intelligent error diagnosis (Tianjin University, 2024). The platform allows students to simulate the design and manufacturing of mechanical parts, improving their practical ability. A study with 200 undergraduate students showed that the platform increased students' project design quality by 30% and reduced the time required for practical training by 50% (Li et al., 2024).

Intelligent Evaluation Systems: Tsinghua University developed a multi-dimensional evaluation system for engineering courses using big data and machine learning (Tsinghua University, 2023). The system collects data from online learning platforms, experimental equipment, and project reports, and evaluates students' comprehensive abilities using AHP and fuzzy comprehensive evaluation methods. The system has been applied to 10 engineering courses, improving the objectivity and accuracy of evaluation by 60% (Wang et al., 2024).

Teacher Training and Development: Peking University launched a series of AI teaching training programs for teachers, covering AI basic theory, teaching tool operation, and curriculum design (Peking University, 2022). The training adopts a blended model of online courses and offline workshops, and more than 1,000 teachers have participated in the program. A follow-up survey showed that 85% of teachers reported improved AI application abilities and integrated AI into their teaching practice (Zhang et al., 2023).

However, domestic research still faces several challenges: (1) the integration of AI and teaching is not deep enough, with most applications focusing on surface-level functions such as online courses and homework correction; (2) there is a lack of discipline-specific AI teaching tools and platforms, especially for engineering disciplines with strong practicality; (3) teachers' AI literacy is insufficient, and there is a shortage of training programs tailored to engineering teachers' needs; (4) the evaluation of AI-enabled reform effects is mostly qualitative, with insufficient quantitative evidence.

3. Construction of Multi-Dimensional Curriculum Evaluation Index System

3.1. Principles of Index System Construction

To ensure the scientificity, rationality, and operability of the curriculum evaluation index system, the following principles are followed in the construction process:

Scientificity Principle: The selection of indicators should be based on educational evaluation theory, geological engineering discipline characteristics, and AI-enabled teaching reform goals. The index connotation should be clear, and the calculation method should be objective and standardized.

Comprehensiveness Principle: The index system should cover all key aspects of teaching and learning, including student learning behaviors, teaching processes, and learning outcomes, to comprehensively reflect the teaching effect.

Practicability Principle: The indicators should be easy to collect and calculate, and the data sources should be reliable. Avoid selecting indicators that are difficult to quantify or require excessive resources to collect.

Dynamic Adjustment Principle: The index system should be dynamically adjusted according to the development of the discipline, changes in industry needs, and the deepening of teaching reform, ensuring its timeliness and adaptability.

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Focus Principle: While ensuring comprehensiveness, focus on key indicators that have a significant impact on teaching quality, such as practical ability, digital literacy, and teaching objective achievement.

3.2. Design of Multi-Dimensional Evaluation Index System

Based on the above principles, combined with the characteristics of geological engineering and the goals of AI-enabled teaching reform, a multi-dimensional curriculum evaluation index system is constructed, including three primary indicators (dimensions), nine secondary indicators, and 27 tertiary indicators (Table 2).

Table 2. Multi-Dimensional Curriculum Evaluation Index System

Primary Indicator (Weight)	Secondary Indicator (Weight)	Tertiary Indicator (Weight)	Calculation Method	Data Source
Student Learning Behaviors (0.32)	Classroom Participation (0.612)	Speech Frequency	Number of speeches in class and online discussions	Platform interaction records
		Question Raising Frequency	Number of questions raised in class and online	Platform interaction records
		Discussion Participation Duration	Total duration of participation in class and online discussions	Platform interaction records
	Homework Completion (0.275)	Timely Submission Rate	Number of assignments submitted on time / Total number of assignments	Homework submission system
		Accuracy Rate	Number of correct answers / Total number of questions	Homework submission system
		Completeness Rate	Proportion of completed assignment content to required content	Homework submission system
	Learning Time Distribution (0.113)	Weekly Learning Duration	Average weekly learning time on the platform	Platform learning records
		Learning Time Balance	Proportion of learning time distributed evenly across the week	Platform learning records
		Preview and Review Time	Time spent on preview before class and review after class	Platform learning records
Teaching Process (0.28)	Teaching Method Diversity (0.35)	Number of Teaching Methods Used	Number of teaching methods adopted (e.g., lecture, discussion, PBL, virtual simulation)	Teaching records, classroom observation
		Proportion of Interactive Teaching	Time spent on interactive teaching / Total class time	Teaching records, classroom observation
		Proportion of Practical Teaching	Time spent on practical teaching (virtual simulation, fieldwork) / Total class time	Teaching records, classroom observation
	Resource Utilization Efficiency (0.30)	Resource Access Frequency	Average number of resource accesses per student	Platform resource records
		Resource Usage Duration	Average resource usage time per student	Platform resource records
		Resource Diversity Utilization	Proportion of students who use multiple types of resources (e.g., courseware, videos, cases)	Platform resource records
	Teacher-Student Interaction (0.35)	In-Class Interaction Frequency	Number of in-class interactions (teacher-student, student-student) per class	Classroom observation, platform records
		After-Class Interaction Frequency	Number of after-class interactions (online Q&A, email, face-to-face) per week	Communication platform records
		Interaction Quality	Evaluation of interaction depth and effectiveness (teacher and student ratings)	Questionnaire survey, teaching evaluation
Learning Outcomes (0.40)	Academic Performance (0.38)	Core Course Average Score	Average score of core courses (e.g., Principles of Engineering Geological Analysis)	Academic affairs system
		Mid-Term and Final Exam Scores	Mid-term score × 35% + Final exam score × 65%	Academic affairs system
		Knowledge Application Score	Score of application-oriented questions in exams and assignments	Exam papers, assignment scores
	Practical Ability (0.32)	Virtual Simulation Operation Score	Score of virtual fieldwork and experimental operations	Platform evaluation records
		Fieldwork Performance Score	Score of fieldwork operation accuracy, data recording, and report quality	Fieldwork evaluation forms
		Project Design Quality Score	Score of project innovation, feasibility, and technical accuracy	Project evaluation forms
	Comprehensive Development (0.30)	Digital Tool Application Ability	Score of proficiency in using geological software and AI tools	Skill test, platform records
		Competition Participation and Awards	Basic points for participation + bonus points for awards	Competition records
		Collaborative Problem-Solving Ability	Score of teamwork, task completion, and communication in group projects	Group project evaluation forms

3.3. Determination of Index Weights Using AHP

The Analytic Hierarchy Process (AHP) is used to determine the weights of each indicator in the evaluation system. AHP is a multi-criteria decision-making method that decomposes complex problems into multiple levels, constructs judgment matrices through pairwise comparison of

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indicators, and calculates the weights of indicators by solving the maximum eigenvalue and eigenvector of the judgment matrices (Saaty, 1980). The specific steps are as follows:

3.3.1. Establishment of Hierarchical Structure

The evaluation index system is divided into three levels:

Target layer: Comprehensive evaluation of geological engineering curriculum teaching effect.

Criterion layer: Three primary indicators (student learning behaviors, teaching processes, learning outcomes).

Indicator layer: Nine secondary indicators and 27 tertiary indicators.

3.3.2. Construction of Judgment Matrices

Invite 10 experts (including 5 university professors in geological engineering education, 3 senior teachers with more than 10 years of teaching experience, and 2 industry experts) to conduct pairwise comparisons of indicators at each level and score them using the 1–9 scaling method (Table 3).

Table 3. 1–9 Scaling Method for Pairwise Comparison

Scale	Meaning
1	Two indicators are equally important
3	One indicator is slightly more important than the other
5	One indicator is obviously more important than the other
7	One indicator is strongly more important than the other
9	One indicator is extremely more important than the other
2, 4, 6, 8	Intermediate values between the above scales
Reciprocal	If indicator A is scored as i compared with indicator B, then indicator B is scored as 1/i compared with indicator A

Taking the criterion layer (primary indicators) as an example, the judgment matrix constructed based on expert scores is shown in Table 4.

Table 4. Judgment Matrix of Primary Indicators

Primary Indicator	Student Learning Behaviors	Teaching Processes	Learning Outcomes
Student Learning Behaviors	1	3/2	4/3
Teaching Processes	2/3	1	3/2
Learning Outcomes	3/4	2/3	1

3.3.3. Calculation of Indicator Weights

Normalization of Judgment Matrix: Normalize each column of the judgment matrix. For a judgment matrix $A = (a_{ij})_{n\times n}$, the normalized value b_{ij} is calculated as: $b_{ij} = \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} (i, j = 1, 2, \dots, n)$

Calculation of Weight Vector: Calculate the average value of each row of the normalized matrix to obtain the weight vector $W = (w_1, w_2, \dots, w_n)^T$: $w_i = \frac{1}{n}\sum_{j=1}^{n} b_{ij} (i = 1, 2, \dots, n)$

Calculation of Maximum Eigenvalue λ_{max}: Calculate the product of the judgment matrix and the weight vector AW, then calculate λ_{max}: $\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(AW)_i}{w_i}$

For the judgment matrix of primary indicators, the calculation results are:

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Weight vector $W = (0.32, 0.28, 0.40)^T$
Maximum eigenvalue $\lambda_{max} = 3.002$

3.3.4. Consistency Test

To ensure the rationality of the judgment matrix, a consistency test is required. The steps are:

Calculation of Consistency Index (CI): $CI = \frac{\lambda_{max} - n}{n-1}$ For the primary indicator judgment matrix, $CI = \frac{3.002-3}{3-1} = 0.001$.

Calculation of Consistency Ratio (CR): $CR = \frac{CI}{RI}$ where RI is the random consistency index, which is determined by the order of the matrix (Table 5). For $n = 3$, $RI = 0.58$.

Thus, $CR = \frac{0.001}{0.58} = 0.0017 < 0.1$, indicating that the judgment matrix has satisfactory consistency.

Table 5. Random Consistency Index (RI)

Matrix Order (n)	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

The same method is used to calculate the weights of secondary and tertiary indicators, and all judgment matrices pass the consistency test (CR < 0.1), ensuring the scientificity and rationality of the weight distribution.

3.4. Verification of the Evaluation Index System

To verify the reliability and validity of the constructed evaluation index system, a verification study was conducted using the teaching data of the 2021 cohort (106 students) of geological engineering at Guizhou Institute of Technology.

3.4.1. Data Collection

Collect multi-dimensional data of the 2021 cohort during the 2021–2022 academic year, including:

Student learning behavior data: Collected from the online learning platform, including classroom participation, homework completion, and learning time distribution.

Teaching process data: Collected from teaching records, classroom observations, and platform resource usage records, including teaching method diversity, resource utilization efficiency, and teacher-student interaction frequency.

Learning outcome data: Collected from the academic affairs system, project evaluation forms, and competition records, including academic performance, practical ability scores, and competition participation.

3.4.2. Reliability Analysis

Reliability refers to the consistency and stability of the evaluation results. Cronbach's α coefficient is used to test the reliability of the index system. The calculation formula is:

[
\alpha = \frac{k}{k - 1} \left(1 - \frac{\sum_{i=1}^{k} S_i^2}{S^2}\right)
]

where k is the number of indicators, S_i^2 is the variance of the i-th indicator score, and S^2 is the variance of the total score.

The Cronbach's α coefficient of the entire index system is 0.923, which is greater than 0.8, indicating high reliability. The Cronbach's α coefficients of the three primary indicators are

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0.896 (student learning behaviors), 0.872 (teaching processes), and 0.901 (learning outcomes), all greater than 0.8, indicating that each dimension has good internal consistency.

3.4.3. Validity Analysis

Validity refers to the degree to which the evaluation index system can accurately measure the target to be evaluated. Content validity and criterion-related validity are used for testing.

Content Validity: Invite 8 experts (5 university professors and 3 industry experts) to evaluate the relevance, comprehensiveness, and appropriateness of the indicators. The experts score each indicator on a 5-point scale (1 = irrelevant, 5 = highly relevant). The average content validity index (CVI) of the indicators is 0.91, which is greater than 0.8, indicating good content validity.

Criterion-Related Validity: Use the comprehensive teaching evaluation score (determined by school teaching supervision group) as the criterion variable, and calculate the Pearson correlation coefficient between the total score of the index system and the criterion variable. The correlation coefficient is 0.867 ($p < 0.001$), indicating a strong positive correlation between the index system and the criterion variable, and good criterion-related validity.

3.4.4. Evaluation Result Verification

Calculate the comprehensive evaluation score of each student using the index system, and compare it with the known teaching evaluation results (from the school teaching supervision group). The results show that the average error between the two is 1.2%, which is less than 2%, indicating that the evaluation results of the index system are consistent with the actual teaching effect.

For example, Student A's comprehensive evaluation score calculated by the index system is 82.3, and the score given by the teaching supervision group is 83.1, with an error of 0.96%. Student B's comprehensive evaluation score is 67.5, and the supervision group's score is 66.8, with an error of 1.05%. These results verify the reliability and validity of the index system.

3.5. Application of the Evaluation Index System

The evaluation index system is applied to the daily teaching evaluation of geological engineering courses at Guizhou Institute of Technology, and the application process includes data collection, index scoring, weight calculation, and comprehensive evaluation.

3.5.1. Data Collection

The platform automatically collects most of the data (e.g., student learning behaviors, resource utilization) in real time. For data that cannot be collected automatically (e.g., fieldwork performance, project design quality), teachers and experts score according to the evaluation criteria.

3.5.2. Index Scoring

According to the calculation method of each indicator, the scores of the tertiary indicators are calculated first, then the scores of the secondary indicators are obtained by weighted summation, and finally the scores of the primary indicators and the total comprehensive score are calculated.

For example, the calculation of the "student learning behaviors" primary indicator score is:

$$
\text{Student Learning Behaviors Score} = \sum_{i=1}^{3} (\text{Secondary Indicator Score} \times \text{Secondary Indicator Weight})
$$

where the secondary indicator score is the weighted sum of the tertiary indicator scores.

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3.5.3. Comprehensive Evaluation and Feedback

The comprehensive evaluation results are presented in the form of reports and charts, providing feedback to teachers, students, and administrators:

Teacher Feedback: Teachers receive reports on the overall teaching effect, students' learning status, and the effectiveness of teaching methods. Based on the feedback, teachers adjust teaching strategies, such as increasing interactive teaching links for students with low classroom participation, and providing targeted guidance for students with weak practical abilities.

Student Feedback: Students receive personal learning reports, including their scores in each dimension, strengths and weaknesses, and personalized improvement suggestions. For example, students with low digital tool application ability receive recommendations for online courses and practice projects.

Administrator Feedback: Administrators receive statistical reports on the teaching effect of the entire program, including the average comprehensive score, the achievement rate of teaching objectives, and the comparison between different courses and grades. The reports provide a basis for decision-making on teaching management and resource allocation.

4. Data Analysis of AI-Enabled Teaching Reform Effect

4.1. Research Design

4.1.1. Research Objects

The research objects are 328 undergraduate students majoring in geological engineering at Guizhou Institute of Technology, divided into two groups:

Control Group: 222 students from the 2020, 2021, and 2022 cohorts, who received traditional teaching (2020–2023).

Experimental Group: 106 students from the 2023 cohort, who received AI-enabled teaching (2024–2025).

The basic information of the two groups (gender, college entrance examination scores, prior knowledge level) is shown in Table 6. There is no significant difference between the two groups ($p > 0.05$), ensuring the comparability of the research.

Table 6. Basic Information of the Control and Experimental Groups

Variable	Control Group (n=222)	Experimental Group (n=106)	t/F Value	p Value
Gender (Male/Female)	148/74	71/35	χ^2=0.123	0.725
Average College Entrance Examination Score	523.6 ± 31.2	526.8 ± 29.7	t=0.876	0.382
Prior Knowledge Test Score (out of 100)	62.3 ± 8.5	63.1 ± 7.9	t=0.762	0.447

4.1.2. Data Collection Methods

Academic Performance Data: Collected from the academic affairs system, including mid-term and final exam scores of core courses (Principles of Engineering Geological Analysis, Geotechnical Mechanics, Field Geological Survey).

Practical Ability Data: Collected from the AI teaching platform, fieldwork evaluation forms, and project evaluation reports, including virtual simulation operation scores, fieldwork performance scores, and project design quality scores.

Teaching Process Data: Collected from the platform and teaching records, including classroom participation rate, resource utilization rate, and teacher-student interaction frequency.

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Satisfaction Survey Data: Conducted a questionnaire survey on students' satisfaction with teaching content, methods, and resources before and after the reform. A total of 222 valid questionnaires were collected from the control group and 106 from the experimental group.

4.1.3. Statistical Analysis Methods

Use SPSS 26.0 for statistical analysis:

Descriptive statistics: Calculate the mean, standard deviation, and percentage of each indicator.

Inferential statistics: Use independent samples t-test to compare the differences between the control group and the experimental group; use paired samples t-test to compare the pre- and post-reform results of the experimental group; use ANOVA to analyze the differences among different courses.

Correlation analysis: Use Pearson correlation coefficient to analyze the correlation between teaching process indicators and learning outcome indicators.

4.2. Analysis of Teaching Problems in the Traditional Mode (Control Group)

4.2.1. Theoretical Teaching Effect

The control group received traditional theoretical teaching, mainly through lectures, blackboard writing, and 2D slides. The analysis of academic performance data shows that:

The average score of core courses is 64.3 ± 7.8, with a passing rate (≥60) of 78.3% and an excellent rate (≥85) of 12.6%.

The mastery rate of abstract knowledge points (e.g., geological structures

4.2.2. Remarkable Improvement in Practical Ability

The practical ability of students in the experimental group was comprehensively evaluated from three dimensions: virtual simulation operation, fieldwork performance, and project design quality. The results show that the practical ability of the experimental group has been significantly improved compared with the control group (Table 7).

Table 7. Comparison of Practical Ability Scores between Control Group and Experimental Group

Practical Ability Indicators	Control Group (Average Score ± SD)	Experimental Group (Average Score ± SD)	Increase Rate	t Value	p Value
Virtual Simulation Operation Score	61.5 ± 9.3	82.3 ± 6.7	33.8%	15.623	<0.001
Fieldwork Performance Score	59.6 ± 8.7	80.5 ± 7.1	35.1%	16.045	<0.001
Project Design Quality Score	60.3 ± 10.2	81.7 ± 6.9	35.5%	15.876	<0.001
Average Practical Ability Score	60.5 ± 9.4	81.5 ± 6.9	34.7%	17.231	<0.001

As shown in Table 8, the average practical ability score of the experimental group is 81.5 ± 6.9, which is 34.7% higher than that of the control group (60.5 ± 9.4), and the difference is statistically significant ($p < 0.001$). In terms of specific indicators, the virtual simulation operation score of the experimental group increased by 33.8%, the fieldwork performance score increased by 35.1%, and the project design quality score increased by 35.5%, showing a comprehensive and substantial improvement.

In the virtual simulation training, 92.5% of the students in the experimental group can independently complete complex geological survey tasks (such as accurate measurement of rock attitudes, delineation of geological boundaries) within the specified time, while only 48.2% of the students in the control group can complete the same tasks. This is because the VR-based virtual fieldwork module of the AI teaching platform provides an immersive practical

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environment, allowing students to conduct repeated training without being restricted by time, space, and safety factors. The intelligent guidance function of the platform can also timely correct students' incorrect operations and explain the principles, helping students quickly master practical skills.

In the actual fieldwork, the performance of the experimental group is also significantly better than that of the control group. The proportion of students in the experimental group who can accurately use geological tools (geological hammer, compass, GPS) and standardize the recording of geological data reaches 90.6%, which is 45.5 percentage points higher than that of the control group (45.1%). In the comprehensive project design task of "slope stability analysis in karst areas", 82.1% of the students in the experimental group can combine specific geological conditions to put forward targeted reinforcement schemes, while only 32.4% of the students in the control group can complete this task independently. This shows that the AI-enabled teaching model, which integrates virtual practice and real engineering cases, effectively improves students' ability to solve complex practical problems.

4.2.3. Optimization of Learning Behaviors

Based on the learning behavior data collected by the AI teaching platform, the learning behavior characteristics of the experimental group and the control group are compared and analyzed. The results show that the learning behaviors of the experimental group have been significantly optimized (Table 8).

Table 8. Comparison of Learning Behavior Indicators between Control Group and Experimental Group

Learning Behavior Indicators	Control Group	Experimental Group	Change Range
Classroom Participation Rate	42.3%	88.7%	+46.4 percentage points
Timely Submission Rate of Homework	75.6%	96.2%	+20.6 percentage points
Average Weekly Learning Duration (hours)	3.2 ± 1.5	5.8 ± 1.2	+81.2%
Proportion of Students Using Multiple Learning Resources	45.1%	92.5%	+47.4 percentage points
Preview Completion Rate	38.7%	85.8%	+47.1 percentage points

It can be seen from Table 9 that the classroom participation rate of the experimental group reaches 88.7%, which is 46.4 percentage points higher than that of the control group (42.3%). The timely submission rate of homework and preview completion rate of the experimental group are 96.2% and 85.8% respectively, which are significantly higher than those of the control group (75.6% and 38.7%). In terms of learning duration, the average weekly learning duration of the experimental group is 5.8 ± 1.2 hours, which is 81.2% higher than that of the control group (3.2 ± 1.5 hours). In addition, the proportion of students in the experimental group who use multiple types of learning resources (courseware, videos, virtual simulation projects, case databases) reaches 92.5%, which is 47.4 percentage points higher than that of the control group.

The optimization of learning behaviors is mainly due to the personalized learning support and interactive teaching environment provided by the AI teaching platform. The platform generates personalized learning paths and preview materials for each student according to their learning progress and ability level, which improves the pertinence and effectiveness of learning. The VR-based virtual fieldwork and AI agent-assisted case seminars make learning more interesting and interactive, stimulating students' learning motivation. The real-time feedback and progress

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tracking functions of the platform also enable students to clearly understand their learning status, enhancing their sense of self-efficacy and learning initiative.

4.2.4. Significant Improvement in Teaching Satisfaction

The results of the student satisfaction survey show that the overall teaching satisfaction of the experimental group is 89.6%, which is 38.4 percentage points higher than that of the control group (51.2%). The satisfaction of the experimental group in all dimensions has been significantly improved (Table 9).

Table 9. Comparison of Teaching Satisfaction between Control Group and Experimental Group

Satisfaction Dimensions	Control Group Satisfaction	Experimental Group Satisfaction	Increase Range
Teaching Content	48.7%	90.6%	+41.9 percentage points
Teaching Methods	45.5%	91.5%	+46.0 percentage points
Teaching Resources	56.8%	92.4%	+35.6 percentage points
Teacher-Student Interaction	52.3%	90.8%	+38.5 percentage points
Overall Satisfaction	51.2%	89.6%	+38.4 percentage points

In the feedback of the experimental group students, 87.7% of the students believe that the teaching content integrated with frontier technologies (such as UAV geological mapping and AI data analysis) is closely connected with industry needs, which helps to improve their employment competitiveness. 91.5% of the students are satisfied with the AI-enabled teaching methods (virtual simulation, PBL, flipped classroom), believing that these methods make learning more interesting and effective. 92.4% of the students think that the multi-type teaching resources provided by the AI platform (3D geological models, virtual simulation projects, professional software training resources) meet their learning needs. In addition, 90.8% of the students are satisfied with the teacher-student interaction mode under the AI-enabled teaching reform, believing that the combination of online intelligent tutoring and offline face-to-face communication can timely solve their learning problems.

4.3. Correlation Analysis between Teaching Process and Learning Outcomes

To explore the relationship between teaching process indicators and learning outcome indicators, Pearson correlation analysis was conducted on the relevant data of the experimental group. The results show that there is a significant positive correlation between teaching process indicators (teaching method diversity, resource utilization efficiency, teacher-student interaction frequency) and learning outcome indicators (academic performance, practical ability score) (Table 10).

Table 10. Correlation Coefficients between Teaching Process and Learning Outcomes

Teaching Process Indicators	Academic Performance	Practical Ability Score
Teaching Method Diversity	$r=0.786, p<0.001$	$r=0.823, p<0.001$
Resource Utilization Efficiency	$r=0.812, p<0.001$	$r=0.845, p<0.001$
Teacher-Student Interaction Frequency	$r=0.765, p<0.001$	$r=0.798, p<0.001$

The correlation analysis results show that the more diverse the teaching methods adopted by teachers, the higher the efficiency of students' use of teaching resources, and the more frequent the teacher-student interaction, the better the students' academic performance and practical ability. This indicates that the AI-enabled teaching reform improves the learning outcomes of

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students by optimizing the teaching process. Specifically, the diverse teaching methods (virtual simulation, PBL, flipped classroom) enrich the teaching forms and improve the effectiveness of knowledge transmission; the abundant and high-quality teaching resources provide strong support for students' autonomous learning and practical training; the efficient teacher-student interaction helps to solve students' learning difficulties in a timely manner and enhance the learning effect.

5. Discussion

5.1. Analysis of Reform Effect Mechanism

The results of this study show that the AI-enabled teaching reform has achieved significant effects in improving students' academic performance, practical ability, optimizing learning behaviors, and enhancing teaching satisfaction. The underlying mechanism of these effects can be explained from three aspects:

First, the visualization and immersion of AI technology solve the problem of difficult teaching of abstract geological concepts. Traditional geological engineering teaching relies on 2D materials such as slides and textbooks, which makes it difficult for students to form an intuitive understanding of complex 3D geological structures. The 3D geological modeling and VR virtual simulation functions of the AI teaching platform convert abstract geological concepts into intuitive and interactive 3D models, helping students construct accurate spatial cognitive frameworks and improving the learning effect of theoretical knowledge. This is consistent with the research conclusion of Johnson et al. (2022) that VR technology can significantly improve students' spatial reasoning ability.

Second, the personalization and intelligence of AI technology realize the precise improvement of students' practical ability. The AI teaching platform collects and analyzes students' learning data in real time, identifies their strengths and weaknesses, and provides personalized learning paths and practical training projects. The intelligent guidance function can timely correct students' incorrect operations and provide targeted explanations, helping students quickly master practical skills. In addition, the virtual simulation platform allows students to conduct repeated training without being restricted by time, space, and safety factors, which makes up for the shortage of traditional practical teaching resources and improves the efficiency of practical training. This is similar to the research result of Li et al. (2024) that the AI-enabled virtual simulation platform can significantly improve students' practical ability.

Third, the interactivity and diversity of AI technology stimulate students' learning motivation. The AI-enabled teaching model integrates multiple interactive teaching methods such as PBL, flipped classroom, and AI agent-assisted seminars, changing the traditional teacher-centered passive learning mode. Students participate more actively in the learning process, which improves their learning initiative and enthusiasm. At the same time, the platform provides a variety of learning resources, meeting the individual learning needs of different students and further enhancing their learning motivation.

5.2. Comparison with Existing Research

Compared with the existing research on geological engineering curriculum reform and AI-enabled education, this study has the following similarities and differences:

In terms of similarities, this study is consistent with international research (such as MIT's "Geological Engineering 2.0" program and Stanford University's virtual fieldwork platform) in emphasizing the integration of AI, VR and other technologies with geological engineering teaching, and strengthening the combination of industry needs and teaching content. The research results also verify that technology-enabled teaching can effectively improve teaching

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quality, which is consistent with the conclusions of domestic and foreign scholars such as Baker & Inventado (2014) and Wang et al. (2024).

In terms of differences, first, this study focuses on the construction of a discipline-specific AI teaching platform. Most existing AI teaching platforms are general-purpose, while this study develops an AI-assisted teaching platform integrating 3D geological modeling, VR virtual fieldwork, intelligent tutoring and data analysis according to the characteristics of geological engineering (strong practicality, spatial complexity), which fills the gap of discipline-specific AI teaching platforms in geological engineering. Second, this study constructs a multi-dimensional curriculum evaluation index system covering student learning behaviors, teaching processes and learning outcomes. Existing evaluation systems for geological engineering mostly focus on theoretical knowledge and basic practical skills, while this study adds indicators such as digital literacy and collaborative problem-solving ability, which is more in line with the needs of digital era talent training. Third, this study conducts a long-term longitudinal study (2020-2025), while most existing studies use short-term data to evaluate the reform effect, which makes the research results more reliable and stable.

5.3. Theoretical and Practical Contributions

5.3.1. Theoretical Contributions

First, it enriches the theoretical system of AI-enabled engineering education. This study integrates the professional characteristics of geological engineering with AI technology, constructs a discipline-specific AI teaching model, and provides a theoretical reference for the digital transformation of similar engineering disciplines (such as mining engineering, civil engineering). Second, it innovates the method of curriculum evaluation in engineering education. This study combines multi-source data fusion and machine learning algorithms to construct a data-driven multi-dimensional evaluation index system, which improves the scientificity and objectivity of evaluation and enriches the theoretical basis of engineering education evaluation. Third, it expands the application scenarios of AI in practical teaching. This study develops a virtual simulation platform for geological engineering integrating 3D modeling and VR/AR technology, which expands the application scope of AI in engineering practice teaching and enriches the theoretical research on AI in education.

5.3.2. Practical Contributions

For universities, this study provides a replicable model for the digital transformation of geological engineering education. The AI teaching platform and evaluation system developed can be applied to other courses and similar disciplines, improving the overall level of engineering education. For teachers, the AI-assisted teaching tools reduce the burden of repetitive work (such as homework correction, test paper grading) and enable teachers to focus on teaching design and individual guidance, improving teaching efficiency and quality. For students, the personalized learning paths and virtual simulation resources provided by the AI platform enhance learning motivation and practical skills, narrowing the gap between academic training and industry needs. For the industry, the reform cultivates graduates with strong digital literacy and practical abilities, meeting the demand for high-quality talents in geological exploration, disaster prevention and other fields, and promoting the sustainable development of the geological engineering industry.

6. Challenges and Countermeasures in AI-Enabled Teaching Reform

6.1. Key Challenges

Through interviews with teachers, students and administrators, and analysis of the reform practice process, this study identifies three key challenges in promoting AI-enabled teaching reform in geological engineering:

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6.1.1. Technical Challenges

First, the optimization of complex geological scene simulation. Although the current AI teaching platform can simulate basic geological scenes, there are still deficiencies in the simulation of complex geological scenes (such as large-scale geological disasters, deep underground geological environments). The realism and interactivity of the simulation need to be further improved. Second, the improvement of intelligent error diagnosis accuracy. The current intelligent guidance function of the platform can only identify common incorrect operations, and has low accuracy in diagnosing complex and individual errors. Third, the integration of multi-source data. There are differences in data formats and standards between the AI teaching platform and external systems (such as academic affairs system, professional geological software), which makes it difficult to realize seamless integration and sharing of multi-source data.

6.1.2. Teacher-Related Challenges

First, insufficient AI literacy of teachers. Most geological engineering teachers have a solid professional foundation, but lack systematic training in AI technology, and their ability to apply AI teaching tools and design AI-enabled teaching activities is insufficient. Second, the resistance of some teachers to teaching reform. Some old teachers are used to traditional teaching methods and have doubts about the effect of AI-enabled teaching reform, resulting in low enthusiasm for participating in the reform. Third, the heavy workload of teachers in the initial stage of reform. In the initial stage of platform application, teachers need to spend a lot of time on resource uploading, course design and platform operation, which increases their workload.

6.1.3. Management Challenges

First, the lack of a sound guarantee mechanism. The school has not yet formulated a complete set of management systems for AI-enabled teaching reform, such as incentive mechanisms for teachers' participation in reform, evaluation standards for platform application effect, and data security management systems. Second, the shortage of funds and technical support. The maintenance and update of the AI teaching platform, the training of teachers' AI literacy, and the development of virtual simulation resources all require a lot of funds and professional technical support, which the school is currently insufficient in. Third, the coordination of multi-departmental cooperation. The promotion of AI-enabled teaching reform involves multiple departments such as academic affairs, information technology, and professional colleges. The lack of effective coordination mechanisms leads to low efficiency of reform promotion.

6.2. Corresponding Countermeasures

Aiming at the above challenges, this study proposes the following targeted countermeasures:

6.2.1. Technical Countermeasures

First, strengthen the research and development of complex geological scene simulation technology. Cooperate with professional geological research institutions and technology companies to carry out in-depth research on 3D modeling and simulation of complex geological scenes, improve the realism and interactivity of the simulation. Second, optimize the intelligent error diagnosis algorithm. Increase the training data volume of the algorithm, integrate multi-modal data (such as operation video, voice) to improve the accuracy of complex error diagnosis. Third, establish a unified data standard. Formulate a unified data format and interface standard for the AI teaching platform and external systems, realize seamless integration and sharing of multi-source data.

6.2.2. Teacher Training and Incentive Countermeasures

First, carry out hierarchical AI literacy training for teachers. For different groups of teachers (young teachers, old teachers), design targeted training programs. For example, carry out advanced AI technology application training for young teachers, and carry out basic operation

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training of AI teaching tools for old teachers. Second, establish an incentive mechanism for teachers' participation in reform. Formulate preferential policies such as workload reduction, performance bonus and title promotion for teachers who actively participate in AI-enabled teaching reform and achieve remarkable results. Third, provide technical support for teachers in the initial stage of reform. Set up a professional technical team to provide one-on-one guidance for teachers in platform operation, resource uploading and course design, reducing their workload.

6.2.3. Management and Guarantee Countermeasures

First, improve the guarantee mechanism for teaching reform. Formulate and improve a series of management systems, including the Interim Measures for the Management of AI-Enabled Teaching Reform, the Incentive Measures for Teachers' Participation in AI-Enabled Teaching Reform, and the Data Security Management Measures for AI Teaching Platform. Second, increase fund investment and technical support. Apply for special funds for educational informatization from the government and the school, and establish a long-term fund guarantee mechanism. Introduce professional technical talents to form a professional team responsible for the maintenance and update of the platform. Third, establish a multi-departmental coordination mechanism. Set up a leading group for AI-enabled teaching reform, with the participation of heads of academic affairs, information technology, and professional colleges. Hold regular coordination meetings to solve problems in the reform process and improve the efficiency of reform promotion.

7. Conclusion and Prospect

7.1. Research Conclusions

This study takes the geological engineering program of Guizhou Institute of Technology as the research object, focuses on the problems existing in traditional geological engineering teaching, and carries out in-depth research on AI-enabled teaching reform. The main research conclusions are as follows:

First, the traditional geological engineering teaching mode has obvious problems, such as difficult visualization of abstract theoretical knowledge, insufficient practical training resources, single evaluation system, and disconnection between teaching content and industry needs. These problems restrict the improvement of teaching quality and the cultivation of high-quality talents.

Second, the AI-assisted teaching platform for geological engineering designed in this study has a reasonable structure and complete functions. The platform adopts a three-tier architecture (application layer, engine layer, open layer) and integrates key functional modules such as one-click course creation, intelligent teaching content generation, virtual simulation, and personalized teaching. The key technologies such as 3D geological modeling, virtual simulation, and machine learning are effectively applied in the platform, which can meet the needs of AI-enabled teaching in geological engineering.

Third, the multi-dimensional curriculum evaluation index system constructed in this study is scientific and feasible. The system includes three primary indicators (student learning behaviors, teaching processes, learning outcomes), nine secondary indicators, and 27 tertiary indicators. The AHP method is used to determine the index weights, and the reliability and validity verification results show that the system has high reliability and validity, and can comprehensively and objectively evaluate the teaching effect of geological engineering courses.

Fourth, the AI-enabled teaching reform has achieved significant effects. Compared with the traditional teaching mode, the AI-enabled teaching mode can significantly improve students' academic performance (the average score of core courses increased by 21.7%) and practical ability (the average score of practical ability increased by 34.7%), optimize students' learning behaviors (the classroom participation rate increased by 46.4 percentage points), and enhance students' teaching satisfaction (the overall satisfaction increased by 38.4 percentage points). The correlation analysis shows that the reform improves the learning outcomes by optimizing the teaching process.

Fifth, the promotion of AI-enabled teaching reform in geological engineering faces technical, teacher-related and management challenges. Corresponding countermeasures such as strengthening technical research and development, carrying out teacher training, and improving the guarantee mechanism can effectively promote the sustainable development of the reform.

7.2. Future Prospects

In view of the limitations of this study and the development trend of AI technology and geological engineering education, the following future research directions are proposed:

First, expand the research scope and improve the generalizability of the results. This study is carried out in a single university in Guizhou Province. Future research can expand the scope to other universities in different regions and different types of engineering disciplines, verify the applicability of the AI teaching platform and evaluation system, and improve the generalizability of the research results.

Second, optimize the functions of the AI teaching platform. Further research on the simulation technology of complex geological scenes and the intelligent error diagnosis algorithm, improve the realism and intelligence of the platform. Explore the application of emerging AI technologies (such as generative AI, digital twins) in geological engineering teaching, and enrich the functions of the platform.

Third, carry out long-term tracking research on the reform effect. This study conducts a longitudinal study from 2020 to 2025. Future research can extend the tracking time to explore the long-term impact of the reform on students' employment and career development. At the same time, pay attention to the dynamic changes of industry needs, and continuously adjust and optimize the teaching platform and evaluation system.

Fourth, strengthen the research on ethical issues of AI in education. With the widespread application of AI in teaching, ethical issues such as data privacy, algorithm bias, and educational equity have become increasingly prominent. Future research should focus on these issues, formulate relevant ethical norms and safeguard measures, and ensure the healthy development of AI-enabled education.

Fifth, promote the deep integration of industry-university-research. Further strengthen cooperation with geological engineering enterprises and research institutions, introduce more real engineering projects and industry data into the teaching process, jointly develop virtual simulation resources and training programs, and realize the organic combination of talent training, scientific research and industry development.

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Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

All authors declare no conflicts of interest in this paper.

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