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Research on the Innovative Teaching of Soil Mechanics Course Based on the "PBL Game Dual-Drive" Model

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Abstract: The New Engineering initiative is a significant strategy proposed by the Ministry of Education to respond to the new round of technological revolution and industrial transformation, aiming to cultivate composite engineering talents with interdisciplinary vision, innovation ability, and practical skills. Soil mechanics, as a core foundational course in civil engineering, needs to be closely integrated with the requirements of the New Engineering initiative for "interdisciplinary integration and innovative practice." This paper introduces the innovative teaching practice of the soil mechanics course based on the "PBL Game Dual-Drive" model. By deeply integrating problem-based learning (PBL) with gamified teaching, this study explores how to effectively enhance students' engineering thinking, technical application abilities, and team collaboration spirit, providing an innovative pathway for the cultivation of civil engineering talents under the context of the New Engineering initiative.

Keywords: new engineering, problem-based learning, gamified teaching, teaching innovation, soil mechanics

1. Introduction

With the advancement of the New Engineering initiative, the civil engineering major has set higher requirements for students' interdisciplinary integration abilities, innovation and practical skills, as well as teamwork and communication capabilities. However, the traditional teaching model of soil mechanics focuses primarily on theoretical instruction, lacking the integration of interdisciplinary cases and the establishment of practical components. This has led to difficulties for students in effectively applying the theoretical knowledge they have learned to real-world engineering scenarios. To address this issue, the author and the course team have actively explored innovative teaching models and introduced the "PBL Game Dual-Drive" model to improve the current situation. For example, in the "Interdisciplinary Project-Based Learning" teacher training workshop jointly held by the Haidian District Educational Research Institute and the School of Education at Beijing Normal University, teachers explored methods and strategies for high-quality implementation of project-based learning through combined online and offline training activities (Ministry of Education of the People's Republic of China, 2017). Additionally, Guangzhou Peiwen Foreign Language School has achieved significant educational outcomes by encouraging students to explore knowledge and develop skills through practice using the PBL educational model.

2. Course Background and Student Situation Analysis

2.1 Background of new engineering initiative

Under the New Engineering initiative, students are required to possess interdisciplinary integration capabilities (National Academy of Engineering,

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2005), which involve the fusion of soil mechanics with fields such as environmental science, materials science, and artificial intelligence. Additionally, they must have the ability to innovate and apply practical skills, utilizing cutting-edge technologies like BIM (Building Information Modeling) and big data to optimize solutions for complex engineering problems (Zhao & Frank, 2003). Moreover, teamwork and communication skills are essential to meet the demands of multidisciplinary collaboration and project management. However, traditional soil mechanics teaching remains predominantly focused on theoretical lectures, lacking interdisciplinary cases and practical components. This results in students' difficulty in transferring theoretical knowledge to real-world engineering scenarios and insufficient exposure to new technologies such as intelligent monitoring and numerical simulation.

2.2 Student situation analysis

The soil mechanics course is typically offered in the third year of undergraduate studies. By this stage, students have already acquired foundational knowledge in mathematics, physics, and engineering mechanics. However, they still face challenges in understanding the more specialized content of soil mechanics. In solving practical engineering problems, students often require systematic analysis and methodological guidance. Under the current educational system, there is a deficiency in students' ability to integrate and apply knowledge across foundational disciplines like soil mechanics and emerging fields such as environmental geotechnical engineering and intelligent material design. This limitation restricts their development into the composite talents demanded by the New Engineering initiative.

3. Teaching Pain Points and Solutions

3.1 Teaching pain points

(1) Disconnection between theory and practice

Although students have mastered theoretical formulas in soil mechanics, such as earth pressure calculations and seepage theory, they often lack systematic analysis skills when confronted with real-world engineering scenarios, such as retaining wall design for excavations or foundation settlement control. Surveys indicate that 85% of students struggle to apply consolidation theory to the design of soft soil foundation treatment schemes and have almost no practical understanding of intelligent monitoring technologies (e.g., fiber optic sensing, BIM dynamic simulation) (Savery, 2006; Kuh, 2008).

Root Cause Analysis: Traditional teaching relies heavily on static case studies, lacking dynamic engineering contexts with multiparameter coupling (e.g., slope stability under the combined effects of earthquakes and rainfall). The slow update of textbook content results in a coverage rate of less than 10% for new technologies such as soil parameter inversion algorithms and digital twin platforms in the past five years.

(2) Lack of student proactivity

The traditional "teacher lectures-students listen" model leads to a classroom participation rate of less than 30%, with weak willingness for independent exploration after class. Research by the Ministry of Education indicates that the one-way transmission model constrains the development of "critical thinking and interdisciplinary integration abilities," especially in the application exploration of emerging technologies (e.g., optimizing soil parameters using machine learning).

Psychological Motivation Inquiry: Student feedback reveals that the lack of concrete visualization for abstract theories, such as the failure to transform the mathematical expression of soil constitutive relationships into intuitive strain cloud diagrams, results in a perceived low learning efficacy.

(3) Structural deficiencies in assessment and evaluation system

Imbalanced Ability Assessment: The current evaluation system relies heavily on end-of-term written exams, which account for 60% of the grade, but lacks assessment of core competencies such as engineering decision-making (e.g., selecting retaining wall schemes based on cost-safety balance) and technological innovation (e.g., developing soil parameter optimization algorithms). The "value-added assessment" required by the Ministry of Education's Action Plan has not been implemented, and the team collaboration process (e.g., resolving conflicts in BIM collaborative design) is not quantitatively recorded.

Mismatch with Industry Demands: Feedback from enterprises indicates that current graduates have a competency rate of less than 35% in mastering complex system modeling techniques (e.g., fluid-solid coupling analysis) and applying emerging simulation tools (e.g., PLAXIS 3D), which is significantly below the requirements of interdisciplinary fields for complex system modeling and data processing.

3.2 Solutions

The "PBL Game Dual-Drive" teaching model, which integrates Problem-Based Learning (PBL) with gamified teaching, is introduced to align with the core orientations of the Ministry of Education's "Five Major Actions for Curriculum Teaching Reform" (Dicheva et al., 2015) :

(1) Teaching Methodology Innovation: Drive independent inquiry through a chain of problems (in line with the second measure of the Action Plan);

(2) Digital Empowerment: Strengthen technical application and practical skills using virtual simulation experiments (aligned with the 14th measure);

(3) Evaluation Traction: Develop a diversified assessment framework (consistent with the 10th measure).

(4) Additionally, in accordance with the requirements for national planning textbook construction, a three-dimensional teaching carrier integrating "problem exploration-gamified pathways-digital resources" is developed to address the aforementioned teaching pain points.

4. Innovative Ideas and Measures

4.1 Innovative ideas

The "PBL Game Dual-Drive" model is employed to focus on real-world engineering problems. By leveraging the engaging and interactive nature of gamified teaching (Zichermann and Cunningham, 2011), this approach aims to cultivate students' innovation, practical skills, and interdisciplinary thinking abilities, thereby achieving the goals of the New Engineering initiative. In the process of solving real-world engineering problems, students are encouraged to actively explore, collaborate in teams (Prince, 2004), and engage with emerging technologies, thereby enhancing their comprehensive capabilities.

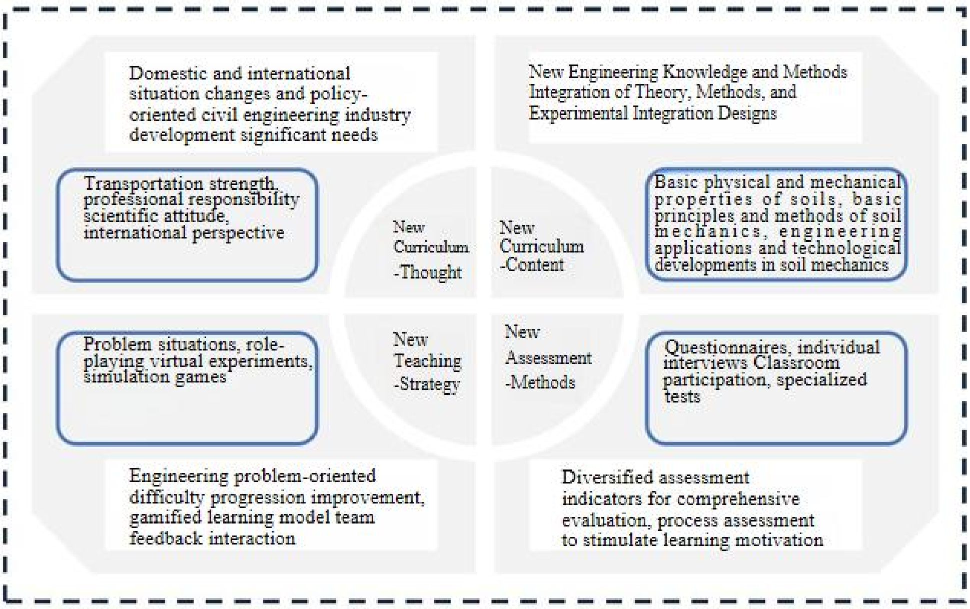

Figure 1 Innovative Thoughts and Implementation

Guided by the “Action Plan for Deepening the Reform of Basic Education Curriculum and Teaching” (Ministry of Education of the People’s Republic of China, 2023), the requirements such as “improving scientific literacy” and “digital empowerment” are integrated into curriculum design:

Problem Design: Aligned with the “Curriculum Implementation Planning Action,” 12 representative typical problems are carefully extracted from national major engineering projects such as the settlement control of the Hong Kong-Zhuhai-Macao Bridge and the construction of plateau permafrost railways (Wang & Li, 2019). These problems cover the fields of environmental geotechnical engineering (e.g., remediation of contaminated sites) and intelligent materials (e.g., self-sensing soil), forming composite engineering cases. A “Problem Entropy” evaluation model is established, which assesses problems from three dimensions: complexity, interdisciplinarity, and technological cutting-edge. This ensures that the problems are both challenging and feasible.

Technological Empowerment: In response to the “Digital Empowerment Action,” an interactive geological disaster simulation scenario is constructed. Students can use VR equipment to simulate operations such as drilling sampling and arranging monitoring points. The system will generate real-time soil displacement fields and stress cloud maps, providing intuitive feedback.

Evaluation Reform: The “Integrated Teaching and Evaluation” model is implemented, incorporating team collaboration and technological innovation as core indicators (Kuh, 2008).

Dimension	Core Measures	Policy Basis
Transformation of Teaching Methods	**Construct a three-stage drive of “Problem Chain–Inquiry Chain–Competence Chain”:** 1. Basic Level: A classic problem database (over 200 standardized cases) 2. Intermediate Level: Interdisciplinary projects (e.g., design of a geological disaster early warning system) 3. Advanced Level: Frontier research and development (e.g., optimization of constitutive models using machine learning)	Measure 2 of the Action Plan
Digital Empowerment of Teaching	**Develop three major digital platforms:** 1. VR Geological Laboratory (including fault scanning and triaxial test simulation) 2. Parameter Inversion Gaming System (a points-based soil parameter optimization competition) 3. BIM Collaborative Design Platform (real-time multi-role collaboration)	Measure 14 of the Action Plan
Reconstruction of Evaluation Mechanism	**Establish a “Competence Radar Chart” evaluation system:** 1. Knowledge Application (30%): Project Reports 2. Technological Innovation (25%): Achievements in Algorithm Development 3. Team Collaboration (20%): 360-Degree Peer Evaluation 4. Engineering Ethics (15%): Decision Justification 5. Process Growth (10%): Analysis of Learning Logs	Measure 10 of the Action Plan

Figure 2 The Three-Dimensional Anchoring Framework of the “PBL Game Dual-Drive” Model

4.2 Innovative Measures

4.2.1 Hierarchical design of the PBL problem system

Problem-Oriented to Practical Engineering: Representative soil mechanics problems are extracted from real-world engineering cases, such as foundation settlement and slope stability. These problems integrate knowledge from multiple disciplines, enabling students to gradually master the basic principles and methods of soil mechanics while solving them and enhancing their ability to integrate and apply interdisciplinary knowledge.

Hierarchical Problem Difficulty: Problems are divided into three levels—basic, intermediate, and advanced — according to students' learning capabilities and levels, to meet the diverse learning needs of students and progressively improve their ability to solve complex problems.

Basic Level: Classic soil mechanics problems (e.g., retaining wall design). Based on the Ministry of Education's planned textbook, Soil Mechanics Practical Case Collection, a standardized problem bank has been carefully constructed.

Intermediate Level: Interdisciplinary problems (e.g., the coupling effect of seismic liquefaction and environmental geotechnics). The "authentic context projects" advocated in the Action Plan [5] are introduced, integrating hydrogeological data with intelligent monitoring data.

Advanced Level: Frontier problems in new engineering disciplines (e.g., slope instability early warning based on machine learning). Collaborating with enterprises, real-time monitoring databases are developed for students' modeling training.

Integration of New Engineering Elements: When designing problems, we specifically incorporate elements of new engineering disciplines, such as considering the profound impact of environmental factors on soil mechanics properties and introducing advanced big data analysis methods to achieve precise prediction of soil mechanics parameters.

4.2.2 Integration of gamification elements

Points and Reward System: Students earn points for progress in problem-solving, classroom discussions, and assignment submissions. These points can be exchanged for rich learning resources or small gifts, significantly enhancing their motivation to learn. Additionally, points tasks related to new engineering capabilities are set, such as proposing innovative foundation treatment solutions for extra points.

Role-Playing and Team Collaboration: Students are divided into groups, each representing an engineering team responsible for solving specific soil mechanics problems. Through teamwork, students' communication, collaboration skills, and team spirit are cultivated.

Virtual Experiments and Simulation Games: Utilizing virtual reality (VR) and simulation technologies, soil mechanics virtual experiments and simulation games are developed. Students can conduct experiments and engineering simulations in a virtual environment to enhance their practical experience.

4.2.3 Teaching process design

Pre-Class Preparation: Teachers carefully prepare pre-class materials and design problem scenarios to stimulate students' interest in self-study and guide them to think deeply.

In-Class Teaching: Teachers actively guide students to analyze the preset problems, organize lively discussions, and encourage students to express their unique insights.

Post-Class Activities: Students consolidate and deepen their understanding of the knowledge through a series of well-designed assignments and exercises.

4.2.4. Reform of the assessment and evaluation system

Diversified Evaluation Indicators: A comprehensive evaluation system is established, including regular performance, assignment grades, project grades, and final exam scores, to reflect students' learning process and capability level.

Focus on Process Evaluation: Emphasis is placed on evaluating students' learning process, such as classroom participation, teamwork ability, and problem-solving skills, to motivate students to engage actively in learning.

5. Efficacy of Teaching Innovation Practices

5.1 Significant improvement in student learning outcomes

According to questionnaires and direct student feedback, there has been a marked increase in students' interest and enthusiasm for the soil mechanics course, with a corresponding rise in classroom participation. Students have demonstrated a more solid grasp of theoretical knowledge and a significant enhancement in their ability to solve practical engineering problems. In the final examination, the average score of students improved by 20%, and the rate of excellence rose from 5% to 10%. Additionally, students have shown significant improvement in interdisciplinary thinking, innovation, and practical skills.

5.2 Comprehensive development of student quality

Students' abilities in teamwork, communication, and self-directed learning have been effectively cultivated. Those who have participated in the soil mechanics course have achieved outstanding results in various academic competitions and entrepreneurial activities.

5.3 Continuous improvement of teachers' teaching abilities

After engaging in the practice of the "PBL Game Dual-Drive" model, teachers have renewed their teaching concepts and methods, especially in problem design, classroom management, and student guidance. They have accumulated valuable experience and significantly enhanced their teaching capabilities.

5.4 Widespread application and promotion of teaching achievements

This innovative teaching achievement has been promoted within the university, with many related courses adopting the "PBL Game Dual-Drive" model for reform. Additionally, the achievement has influenced sister departments, providing beneficial references for the reform of soil mechanics teaching.

6. Experience and Reflections on Teaching Innovation Practice

6.1 Successful experiences

Close Integration with Practical Engineering: By introducing real-world engineering problems, students have been made aware of the practicality of soil mechanics knowledge, thereby stimulating their interest and motivation to learn.

Full Play of Students' Subjectivity: Emphasizing students' self-directed learning and teamwork has enabled them to actively acquire knowledge while solving problems, enhancing their learning ability and overall quality.

Skillful Integration of Gamification Elements: The use of points rewards, role-playing, and other elements has increased the fun and challenge of learning, significantly improving student participation and enthusiasm.

Incorporation of New Engineering Elements: The emphasis on integrating new engineering content into the teaching process has cultivated students' interdisciplinary thinking, innovation, and practical skills.

6.2 Areas for improvement

Difficulty Control in Problem Design: If the difficulty of problems is not properly controlled, it can lead to difficulties for students in solving them, thereby affecting learning outcomes.

Moderation of Gamification Elements: Overuse of gamification elements can distract students and hinder the achievement of teaching objectives.

Effectiveness of Teacher Guidance: Sometimes, due to limited teacher capacity, it is not possible to provide timely and effective guidance to each student.

Insufficient Integration of New Engineering Resources: Incomplete resource integration can result in a lack of depth and systematicness in teaching content.

6.3 Measures for improvement

Optimize Problem Design: Reasonably control the difficulty of problems and adjust the difficulty and type of problems in a timely manner based on student feedback.

Moderate Use of Gamification Elements: Reasonably control the frequency and intensity of gamification elements to ensure they effectively promote student learning.

Strengthen Teacher Training: Regularly organize teachers to participate in teaching training and exchange activities to improve their ability to design and guide gamification teaching.

Enhance Integration of New Engineering Resources: Strengthen cooperation with teachers from related disciplines and research institutions to integrate more new engineering resources and enrich teaching content.

Conclusion

The application of the “PBL Game Dual-Drive” model in the teaching of soil mechanics courses has achieved remarkable success in teaching innovation. By integrating problem-based learning with gamification and incorporating elements of new engineering disciplines, this model has successfully addressed the issues of disconnection between theory and practice and lack of student initiative in traditional teaching. It has significantly enhanced students’ learning outcomes and overall quality and promoted the improvement of teachers’ teaching abilities.

Moreover, this model also provides valuable references and examples for the teaching reform of other courses. In future teaching, we will continue to refine and optimize the “PBL Game Dual-Drive” model, constantly improving the teaching quality and standards of soil mechanics courses. We are committed to contributing greater efforts to the cultivation of more high-quality civil engineering talents.

Conflict of interest

The authors declare that they have no conflicts of interest in this work.

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