Research on the empowerment mechanisms and realization pathways of problem-driven learning on engineering competencies

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Abstract: *The continuing advancement of engineering education accreditation necessitates enhanced development of competencies for addressing complex engineering challenges. Prevailing instructional approaches remain constrained by fragmented knowledge delivery, limited contextualization, reduced engagement, and restrictive assessment protocols—barriers that impede the cultivation of interdisciplinary innovative capacities essential in modern engineering education. This study proposes an outcome-oriented framework integrating problem-driven pedagogy, systematically structured through aligned educational objectives, reconfigured content, designed learning tasks, and multidimensional evaluation. Empirical implementation demonstrated strengthened problem identification, knowledge integration, and applied competencies, presenting a referential model and actionable approach for the advancement of engineering pedagogy.*

Keywords: *PBL; OBE; Teaching model; Curriculum reform; Engineering Mechanics*

I. Introduction

From the perspective of the reform and development of engineering education in various countries, the teaching reform of the course *Engineering Mechanics* has become one of the important topics in engineering education research. Based on the concern for students' abilities and qualities, the course *Engineering Mechanics* needs to shift from emphasizing knowledge to focusing on capabilities. Foreign engineering education emphasizes student-centeredness, using scenario-based learning and interdisciplinary integration to cultivate students' engineering analysis abilities in the process of conducting model construction-based, real engineering case analysis, and project-based learning. Engineering education certifications in countries such as the United States and Europe all have high requirements for students' ability to solve complex engineering problems, thereby prompting the course *Engineering Mechanics* to transform from traditional theoretical teaching to a comprehensive teaching method that integrates experiments, simulations, and engineering projects. In recent years, the exploration of the reform of the course *Engineering Mechanics* has gradually begun, and many universities have optimized and improved the existing curriculum system, teaching methods, and informatization. However, overall, there is still insufficient attention to conducting large-scale innovations for the entire system, and there is no systematic *Engineering Mechanics* curriculum system and reform teaching methods, resulting in an insufficient match between students' abilities and engineering practice.

The teaching of the course *Engineering Mechanics* has problems such as excessive theoretical-oriented teaching content, a focus on teacher-led lectures, severe fragmentation of knowledge structure, and a single evaluation method. However, in the context of engineering education accreditation and the construction of new engineering disciplines, the course *Engineering Mechanics* should shift from emphasizing knowledge teaching to highlighting ability orientation, and by adopting engineering scenarios to cultivate students' ability to analyze problems, model, and acquire engineering practice skills, it should be the key focus of future reforms. In addition, engineering education serves as a cornerstone of the higher education system (Zhang, 2022). For these reasons, this study integrates Outcome-Based Education (OBE) principles and Problem-Based Learning (PBL) methodology into the course *Engineering Mechanics*. Through the reconfiguration of outcome-oriented course goals, the design of learning tasks based on engineering problems, and the construction of a multi-dimensional evaluation system, it explores effective paths to solve the current predicament.

II. Reconstruction of Course Objectives under the OBE Framework

Outcome-Based Education (OBE) focuses on learning outcomes and deduces the teaching content, teaching methods, and evaluation methods of the course from the expected learning outcomes in reverse (Rao, 2020; Asim et al., 2021). Based on this, this study first redefines the course objectives of *Engineering Mechanics* according to the training plan of engineering majors. The framework is as follows:

(1) Knowledge objective: Master the concepts, principles, and analysis methods of statics and mechanics of materials.

(2) Ability objective: Have the ability to formulate problems based on specific engineering scenarios, model and solve them, and verify the results.

(3) Quality objective: Not only gradually form a mature engineering thinking mode, but also have teamwork awareness, innovation awareness, and autonomous learning ability.

In addition, based on these objectives, a progressive index system of "knowledge - ability - quality" is reconstructed to link the course content with the graduation requirements, so as to form a quantitative index system

III. Design of PBL-Oriented Instructional Content and Learning Tasks

Problem-Based Learning (PBL) emphasizes taking real engineering projects as the core driving factor for learning (Wood, 2003; Hmelo-Silver et al., 2004). Therefore, this study innovatively designs the "engineering problem chain" learning task model based on the knowledge structure of the course *Engineering Mechanics*.

Development of Learning Projects Based on Authentic Engineering Contexts

During the process of professional education in transportation, the relevant mechanical performance analysis of vehicle body components and transportation equipment parts is a prerequisite for students to understand and master engineering safety and structural reliability. And the knowledge of material mechanics is the core foundation for the force analysis of vehicle body components, structural optimization, and safety performance design (Wong, 2009; Ibrahim, 2004). To enhance the learning of the material mechanics content in the course *Engineering Mechanics* course, some project-based designs targeting actual vehicle structural components will be added, with the aim of enabling students to further understand and master the concepts of stress, strain, strength, stiffness, and structural safety through the process of applying and solving specific mechanical knowledge to solve problems.

The project content includes: conducting simulations for the situation where the longitudinal beams of the car frame are subjected to bending loads during acceleration and braking, and analyzing the stress of different cross-sections (e.g., channel steel type and box-type beams) to deepen the understanding of the structural load-bearing capacity of the car; completing the research on the bending deformation behavior of important body components such as A-pillar and B-pillar under lateral force or top pressure loads, and discussing the impact of buckling and plastic deformation on the overall safety of the vehicle body; conducting strength verification for seat fixing brackets; designing the stress concentration behavior of vehicle hooks or trailer connection points under traction loads, in order to analyze the relationship between transitional design, rounded corners treatment and stress peaks in structural design; taking the vehicle suspension system brackets as the object for fatigue life analysis, and exploring the significance of fatigue characteristics of materials under idealized cyclic loads for vehicle durability.

All the above projects are directly extracted from the practical aspects of vehicle engineering, which makes it easier for students to focus on the study of mechanics of materials. Through the practical training of the projects, by gradually conducting stress analysis on components, building calculation models, checking the structural safety, and optimizing the design, a complete analysis chain of "load - structure - material" can be formed, and it is also conducive to enabling students to apply the knowledge of mechanics of materials they have learned to solve practical problems more fully.

Implementation of Interconnected Problem-Sets in Instructional Design

In the teaching of the course *Engineering Mechanics*, the problem chain teaching mode is utilized to guide students to gradually understand stress analysis, modeling methods, and the reasonable construction of structural optimization schemes. The problem chain teaching method is integrated into task-driven learning activities, enabling students to gradually form a complete knowledge system and enhance their problem analysis abilities in the process of continuous reasoning, thus laying a solid foundation for future teaching.

The problem chain stems from the stress conditions of engineering structural components, such as the internal forces and bending deformations that occur in beams under load. In this teaching mode, students can pay attention to the material properties and dangerous sections of the structure, and on this basis, construct models, conduct calculations, derivations, and result analyses. This indicates that through the entire problem chain teaching, students can gradually develop the ability to comprehensively integrate the entire process from theory to practice.

During the problem chain teaching process, students solve problems through independent analysis or group discussions, thereby gradually understanding the essence of the problem and the related solutions. The teacher uses the method of heuristic questioning - demonstration and explanation - phased feedback to gradually guide students to accurately master the rules of bending moment distribution, the characteristics of stress concentration, and the criteria for judging the yield state. By applying the problem chain teaching method, a sequential design of problems from simple to complex is achieved. This not only enables students to continuously verify the analysis process, adjust model assumptions, compare similarities and differences to seek better methods, but also helps cultivate students' ability to solve complex engineering problems.

IV. Student-Centered Learning and Collaboration

Under the student-centered learning approach, students are the main participants in the teaching process of mechanics of materials, and they should actively explore and reflect on the learning process and conduct self-reflection; teachers are no longer one-way knowledge transmitters, but rather guides and facilitators for students. The design of classroom activities focuses on task-driven, collaborative learning and immediate feedback, enabling the full application of theory to practice.

Group collaborative learning utilizes typical problems from mechanics of materials as the carrier (such as the stress analysis of structural components like beams, columns, and supports), and assigns different roles to students (e.g., modelers and calculators) to work collaboratively. Through this division of labor and cooperation, students can learn methods for model construction, calculation analysis, and result verification, and cultivate their teamwork and engineering communication skills. Throughout the entire teaching process, each group must present the analysis process and results in oral or written form, and pay attention to the rigor of logic, the rationality of data, and engineering explanations. In addition, peer questioning and teacher evaluation are also adopted, which can help students identify errors, correct their thinking, and enhance their analytical skills and critical thinking.

This process should also be supplemented by immediate feedback and finite element software. Classroom immediate feedback and dynamic adjustments are carried out through formative evaluation. Teachers use students' answers, classroom discussions, and example corrections to constantly understand students' learning situations, correct their understanding deviations, and guide students to accurately grasp the key points of learning (e.g., stress concentration, dangerous sections, and yield criteria). Finite element software is a powerful tool for auxiliary analysis. Through finite element simulation, stress maps and strain maps of the actual structure can be obtained. The comparison of these maps with the hand-calculated results enables students to continuously test and improve their analytical abilities in the process of theory - calculation - engineering application.

V. Reform of the Curse Ealuation System

Diversified Assessment Components

The course evaluation content comprehensively covers three aspects: knowledge mastery, ability improvement, and quality cultivation. It not only considers the regular final exams conducted within the school, but also combines the assessment of project reports, periodic assignments, classroom discussion performances, and group collaboration outcomes. This is aimed at specifically examining students' theoretical analysis ability, model construction ability, and problem-solving ability. The project report mainly assesses stress analysis, modeling methods, and engineering conclusions; the periodic assignment mainly assesses the understanding and application of concepts; the classroom discussion mainly assesses thinking logic and language expression ability. Through a comprehensive and process-oriented assessment of students, the effectiveness of their learning of material mechanics and their overall quality level can be accurately determined.

Transparent and Quantifiable Assessment Criteria

To ensure the fairness, impartiality and legality of the evaluation process, the scoring criteria established for this course are divided into six aspects: knowledge acquisition, problem analysis, model establishment, calculation ability, creativity, and teamwork. This is done to make the scoring criteria clear and quantifiable. Each task in the classroom has specific evaluation criteria that are adapted to its characteristics, and the proposed teaching model requires students to clearly understand the evaluation points of each task and the achievable goals. Moreover, the evaluation standards have both qualitative and quantitative attributes. This not only enables students to distinguish the differences between different evaluation criteria, but also allows teachers to score according to the evaluation standards and provide accurate guidance and correct opinions to students, thereby enabling students to clearly identify their strengths and weaknesses, and adjust their learning methods accordingly to cultivate their autonomous learning ability and engineering practice ability. These measures have improved the reliability and operability of the teaching evaluation, thus integrating the teaching objectives of the course with the students' abilities.

Emphasis on Formative Assessment

In the course, the actual abilities and theoretical levels of students are thoroughly examined, which serves as the fundamental driving force for promoting students' continuous self-optimization and development. Specifically, methods such as log learning, stage reports, classroom discussion records, and quizzes are utilized to regularly assess students' understanding of material mechanics knowledge, modeling skills, and problem analysis abilities. Formative assessment not only focuses on results but also pays attention to the process, enabling students to promptly correct their erroneous understandings and knowledge blind spots, and facilitating the transformation of theoretical knowledge into practical applications.

VI. Implementation Outcomes and Analysis of the Instructional Reform

Based on the practical data from a certain university over the past two years, the teaching model proposed in this paper has significantly enhanced students' enthusiasm for active learning. Under this teaching model, the number of classroom interactions and the proportion of students actively seeking materials after class have both achieved remarkable improvements. Moreover, students' problem analysis skills and modeling abilities have been further strengthened. Most students can propose reasonable mechanical hypotheses and complete basic model establishment. Students have a high level of satisfaction with their learning, and the vast majority of students believe that this teaching model helps them understand engineering mechanics knowledge better.

VII. Conclusion and Future Work

Based on the OBE concept, this study has constructed a teaching mode for "Engineering Mechanics" centered on PBL. This teaching mode integrates the three elements of problem-based chain teaching, active learning and collaborative organization, as well as a multi-dimensional evaluation system. The teaching practice results based on this teaching mode indicate that this teaching mode effectively enhances students' problem analysis ability, modeling ability, and engineering application awareness, increases classroom participation and students' learning enthusiasm, thereby achieving the unity of knowledge transmission, ability cultivation, and quality improvement.

In future reforms, based on this teaching mode, not only can the finite element simulation platform be used to simulate higher-order typical engineering scenarios, but also some interdisciplinary and highly comprehensive content can be selected for project design to further implement the effective integration of theory and engineering practice. Moreover, this teaching mode can continuously improve the accuracy and quantifiability of the achievement degree of ability based on the gradual optimization of the evaluation system. This teaching mode provides an operational and specific example for the teaching reform of basic courses in the context of new engineering disciplines, and can also serve as a reference for the improvement of teaching methods and curriculum innovation in other engineering courses.

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