Construction of a Closed-loop Evaluation System and Teaching Reform for Materials Mechanics Course under OBE Orientation — A Driving Model Based on Engineering Cases and Subject Competitions

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Abstract: To address issues in traditional Materials Mechanics course evaluation, such as single-mode assessment, broken feedback mechanisms, and ambiguous goal mapping, this study constructs a closed-loop course objective attainment evaluation system based on the OBE concept, featuring "backward design – multi-dimensional evaluation – dynamic optimization." By decomposing graduation requirements into three hierarchical dimensions—"knowledge, skills, innovation"—and organically integrating engineering cases and subject competition resources, this system leverages intelligent teaching platforms to collect multi-source data, forming a continuous "evaluation-improvement" optimization mechanism. Practice shows that this system significantly strengthens weak teaching areas, substantially enhancing students' engineering application capabilities and competition participation rates, thus providing a replicable implementation path for engineering education curriculum reform.

Keywords: OBE concept; Materials Mechanics; course objective attainment; closed-loop evaluation system; teaching reform

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Introduction

With the advancement of engineering education accreditation, the OBE (Outcome-Based Education) concept has become the core of curriculum reform. Systematically proposed by Spady W.G. [1], this concept emphasizes designing educational systems around students' final learning outcomes. Traditional Materials Mechanics course evaluation faces three major contradictions: excessive reliance on summative exams, which inadequately reflect engineering application capabilities such as component stress analysis; delayed feedback, which fails to promptly identify cognitive weaknesses like application of strength theories; and disconnection between course objectives and industry needs, lacking pathways to translate abstract requirements such as "component load-bearing capacity analysis" into concrete teaching indicators, thereby falling short of ABET's certification standard of "student outcomes as the core" [2]. These issues constrain engineering education quality and urgently require systemic reform.

The OBE concept resolves these problems through a threefold logic: First, "backward design" decomposes graduation requirements step-by-step into operational course objectives—for instance, breaking down "ability to solve complex engineering problems" into specific indicators such as "calculation of bending stress in beams" and "stability verification of compression members" [3]—ensuring alignment with industry needs. Second, "multi-dimensional evaluation" integrates feedback from multiple stakeholders, including teachers, industry mentors, and student self-assessments, constructing a three-dimensional evaluation network covering knowledge, skills, and engineering literacy. Third, the "dynamic feedback" mechanism, based on real-time data from teaching platforms,

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diagnoses teaching weaknesses and forms a closed "evaluation-improvement" loop, promoting precise alignment between course objectives and industry demands.

1.OBE Framework Construction for Materials Mechanics Course Evaluation System

1.1 Backward Design: Objective Deconstruction and Content Reconstruction

OBE backward design follows the reverse derivation logic of "industry demand → graduation requirements → course objectives → teaching content" [4], ensuring linkage between stages through standardized modular design. Based on the "Engineering Education Accreditation Standards" and civil engineering industry demands, graduation requirement indicators are decomposed into quantifiable course objectives (e.g., "engineering problem analysis ability" is broken down into "axial tensile/compressive rod stress calculation" and "combined deformation strength verification"), and mapped to teaching chapters such as "axial deformation" and "strength theory" through a course matrix [5].

In content reconstruction, the traditional separation between theory and practice is overcome through modular reorganization and integration of engineering cases to achieve knowledge integration. Theoretical mechanics (static equilibrium) and materials mechanics (strain analysis) are fused into a competency development chain of "external force → internal force → stress → deformation," incorporating engineering cases such as compression of columns in high-rise buildings and bending of main girders in bridges, transforming industry needs into concrete teaching scenarios [6]. The teaching strategy adopts a "virtual-real integration" approach, using software such as ANSYS for virtual material tensile experiments, establishing a complete cognitive path of "theoretical modeling → simulation verification," and laying a data foundation for the evaluation phase [7].

1.2 Multi-dimensional Evaluation Model: Indicator Construction and Implementation Path

The multi-dimensional evaluation model centers on a three-level mapping of "objective → indicator → assessment," constructing an integrated evaluation system encompassing knowledge, ability, and literacy. In indicator construction, abstract objectives such as "analysis capability of component mechanical behavior" are broken down into observable indicators like accuracy in calculating normal stress in tensile/compressive rods and understanding of torsional shear stress distribution. These correspond to diverse assessment components: theoretical exams (focusing on principle mastery), engineering case analysis (focusing on software application), and subject competitions (focusing on innovative design). Data mining techniques are employed to quantify implicit ability indicators [7]. Evaluation weightings balance knowledge depth and practical ability (e.g., theoretical exam 30%, case modeling 40%, competition results 20%) and incorporate ideological and political education elements within the curriculum [8, 9].

The implementation path integrates qualitative and quantitative evaluation: quantitative evaluation uses the fuzzy comprehensive method to quantify indicator attainment; qualitative evaluation introduces a "triadic feedback" mechanism—student self-assessment to promote reflection, industry mentors participating in competition reviews, and peer teachers optimizing the indicator system via the Delphi method. An innovative "dual-track virtual-real" evaluation tool is developed [10]: virtual platforms record simulation experiment operation trajectories, while physical experiments validate mechanical performance through 3D-printed component loading, forming a dual-track data chain of "process → outcome" to enhance complementarity between formative and summative evaluation.

1.3 Dynamic Feedback Mechanism: Data-driven Strategies and Iterative Optimization

The dynamic feedback mechanism relies on intelligent teaching platforms to build a closed-loop system of "data collection → analysis → intervention → optimization" [11]. Multi-source data from platforms like Rain Classroom and ANSYS simulation logs capture real-time student learning dynamics, which are then cleaned and transformed into unified datasets. The fuzzy comprehensive method quantifies indicator attainment, triggering a three-tier response mechanism when core competency indicators fall below thresholds: Level 1 warnings automatically push targeted learning resources; Level 2 warnings initiate personalized teacher tutoring; Level 3 warnings trigger course revision procedures.

Based on multi-source data, an adaptive teaching strategy model is constructed. Machine learning algorithms precisely match weak indicators—for example, automatically associating "stress concentration analysis" difficulties with an enhanced solution combining "virtual simulation + case review" [12]. Integrating formative evaluation data with graduate tracking feedback, teaching reflection meetings generate improvement checklists, achieving a PDCA (Plan-Do-Check-Act) cycle of "early warning → intervention → verification" [13]. This mechanism upgrades traditional post-hoc evaluation to real-time dynamic intervention, significantly enhancing the precision and timeliness of instructional adjustments [14].

2.Teaching Innovation Pathways Driven by Engineering Cases and Subject Competitions

2.1 Bidirectional Empowerment through Case Library Construction and Teaching Integration

Engineering case library construction follows the principle of "industrial problem pedagogization and teaching content scenarization," building a resource system dynamically aligned with course objectives. Typical engineering scenarios such as reinforcement of aging bridges and design of large-span steel structure joints are selected and decomposed according to the full process of "defect identification → theoretical analysis → scheme design → code verification," forming teaching units covering core knowledge points of Materials Mechanics [15]. Each case corresponds to 3-5 competency indicators—for instance, the "stress concentration treatment at bridge bearings" case links to teaching objectives such as "stress concentration coefficient calculation" and "selection of strength theories," establishing a teaching closed loop of "engineering problem → mechanical model → calculation method → code verification."

Teaching integration employs a "dual-mentor collaboration – virtual-real linkage" model: industry mentors provide real-world measured data and industry standards, while university teachers design task chains guiding students through the full analysis process from load determination to safety verification [16]. Using ANSYS virtual simulation and materials mechanics laboratory equipment, theoretical and practical learning are combined through "virtual simulation of component forces → physical loading verification of performance." The evaluation phase converts industry scoring standards into course assessment indicators, ensuring consistency between case-based teaching and industry needs.

2.2 Innovation in Competency Development through "Course-Competition Integration"

The "course-competition integration" model transforms subject competition standards into gradient-based teaching content, constructing a talent cultivation closed loop of "competition task-driven → curriculum system restructuring → spiral competency enhancement." Taking the National Undergraduate Materials Mechanics Competition as an example [17], competition indicators such as "structural load efficiency" and "lightweight design" are broken down into three-tier course modules—"basic modeling training → simulation optimization → physical prototype fabrication"—corresponding to core Materials Mechanics content on strength, stiffness, and stability, achieving deep alignment between competition standards and teaching objectives [18].

Teaching implementation adopts a "dual-mentor collaboration + problem-chain driven" model: industry mentors provide authentic competition problems and engineering parameters, while university teachers design the teaching chain of "task introduction → scheme comparison → process correction → outcome presentation." For instance, the competition topic of "cantilever beam seismic design" is transformed into a course project, where students undergo progressive training in "theoretical calculation → virtual simulation → physical model fabrication," simultaneously enhancing mechanical analysis skills and engineering innovation literacy. The evaluation mechanism introduces competition scoring rules (e.g., component load-to-mass ratio, deformation coordination) to align course assessment standards with industry evaluation systems [12].

2.3 Technology-enabled Pathways for Virtual-Real Integrated Teaching Tools

The development of virtual-real integrated teaching tools focuses on a competency development chain of "virtual rehearsal → physical verification → digital optimization," overcoming spatiotemporal limitations of traditional practical training. Technologically, it relies on digital twins and AI algorithms to build virtual-real interactive platforms. For example, a virtual simulation system for Materials Mechanics [11] is developed, using 3D modeling to recreate experimental scenarios such as material tension and torsion, strengthening the linkage between virtual tools and physical experiments. Students can complete parameter tuning and scheme optimization in virtual environments, followed by mechanical performance verification using physical experimental equipment, forming a learning closed loop of "virtual trial-and-error → physical verification → digital iteration."

Tool functions encompass three major modules: a virtual simulation resource library (e.g., composite material mechanical property simulation), an intelligent evaluation system (real-time tracking of modeling trajectories and data processing), and virtual-real interaction interfaces (enabling real-time interaction between simulation data and experimental equipment). In application scenarios, it addresses traditional teaching pain points—for example, visualizing high-risk experiments (fatigue failure testing) and microscopic phenomena (crack propagation) through virtual simulation, combined with physical experiments to reinforce operational skills, achieving teaching innovation characterized by "concretizing abstract theories, visualizing complex phenomena, and securing high-risk experiments" [13].

3.Reform Effectiveness and Pedagogical Reflection

3.1 Multi-dimensional Quantitative Effectiveness

After implementing the OBE-oriented evaluation system and teaching reform, the attainment of Materials Mechanics course objectives has significantly improved. Core competency indicators such as "component strength verification ability" and "experimental data processing ability" have markedly increased compared to pre-reform levels. Student participation rates and award-winning project numbers in provincial and above-level Materials Mechanics competitions have multiplied, consistent with Han Yongping et al.'s [10] assertion that diversified evaluation systems incentivize practical abilities. Comprehensive course evaluations show significant improvements in students' engineering case analysis report quality and simulation experiment operational standardization. Graduates' mechanical analysis and problem-solving abilities in their positions have received widespread industry recognition.

Data from intelligent teaching platforms indicate increased average virtual simulation experiment operation duration and significantly improved knowledge point test accuracy. The correlation between formative and summative evaluation scores has strengthened, validating the guiding role of the evaluation system on the learning process. Teachers, based on formative evaluation data, have adjusted teaching strategies [14]—for example, increasing case-based class hours for weak areas such as "combined deformation analysis"—driving continuous optimization of teaching quality.

3.2 Deep Insights from Qualitative Feedback

Student feedback indicates that the engineering case and competition-driven teaching model significantly enhances interdisciplinary integration capabilities and engineering thinking. Over 80% of students understand the engineering value of Materials Mechanics theories through real-world engineering cases, and over 70% master multi-objective optimization decision-making (e.g., balancing component strength and weight) through competitions [15]. Graduate interviews reveal that "course-competition integration" projects directly support their capabilities in actual engineering scheme design and problem diagnosis, confirming the teaching effectiveness of "competency generation" under the OBE concept [19].

University-industry collaborative teaching shortens the update cycle for teachers' engineering practice knowledge. The dual-mentor collaboration model enhances teachers' ability to transform engineering problems into teaching content. Industry mentors note that, post-reform, students' engineering proposals better align with industry standards, and their problem response and technology transfer efficiency have significantly improved [20]. At the educational ecosystem level, the depth and effectiveness of industry-education integration continue to increase, forming a virtuous cycle of win-win cooperation among universities, enterprises, and students.

4.Conclusions and Outlook

The Materials Mechanics course reform based on the OBE concept, through constructing a closed-loop system of "backward design – multi-dimensional evaluation – dynamic feedback," quantifies graduation requirements into course objectives and integrates engineering case and subject competition resources, achieving alignment between teaching content and industry needs. Practice shows that students' core engineering competencies (such as component strength verification and experimental data processing) have significantly improved; provincial and above-level competition participation and awards have multiplied; engineering case analysis and simulation experiment standardization have improved; and graduates' job competencies are recognized by enterprises. Intelligent teaching platform data drives dynamic optimization of teaching strategies, enhancing the correlation between formative and summative evaluation.

Future research will focus on three areas: exploring innovative applications of digital technologies such as the Metaverse and generative AI in virtual simulation teaching; constructing a cross-cycle competency tracking system of "course – major – industry" to deepen evaluation dimensions; and promoting the alignment of reform experiences with international engineering education standards to enhance global competitiveness of talents and serve the national strategy of building a manufacturing powerhouse.

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