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Teaching reform strategies of "Mechanical Equipment Structural Design" course based on OBE concept

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Abstract: To address the new challenges in engineering education posed by the New Engineering Education Initiative, this study investigates the imbalance between theory and practice and insufficient analytical synthesis in "Mechanical Equipment Structural Design" course. Grounded in the Outcomes-Based Education (OBE) framework, we systematically explore pedagogical reform strategies through reverse design principles. The paper first elucidates the core philosophy of OBE, then proposes comprehensive teaching innovations including defining course learning outcomes, restructuring project-based curricula, developing blended learning approaches, and establishing diversified continuous improvement evaluation systems. These reforms aim to transform the course from a traditional "knowledge transmission" model to one emphasizing "competency development". By innovating instructional methods and assessment frameworks, the study seeks to enhance students' comprehensive problem-solving skills and creative thinking in complex engineering scenarios, providing valuable references for similar engineering course reforms.

1. Introduction

"Mechanical Equipment Structural Design" is a core professional course in mechanical engineering, characterized by its comprehensive and highly practical nature. It serves as a crucial component for cultivating students' engineering design and innovation capabilities. However, traditional teaching methods exhibit significant shortcomings: outdated content that fails to keep pace with industry advancements, rigid methodologies limited to teacher-led lectures and passive student absorption, and assessment approaches overly reliant on final written exams that fail to comprehensively evaluate students' integrated design competencies. This results in students acquiring fragmented knowledge that struggles to be synthesized, ultimately leading to deficiencies in analytical, design, and innovative capabilities when confronted with real-world engineering challenges[1,2].

OBE, a student-centered philosophy focused on learning outcomes, has become the cornerstone of international engineering education accreditation. It emphasizes organizing educational processes around students' ultimate competencies[3,4]. Through implementing OBE principles in the core course "Mechanical Equipment Structural Design", this study systematically reformed multiple dimensions including curriculum design, content restructuring, pedagogical innovation, and evaluation systems. By shifting from traditional knowledge-transfer models to competency-driven instruction, we achieved precise alignment between teaching processes and professional skill development. This OBE-based reform not only significantly enhanced classroom effectiveness but also comprehensively developed students' engineering practice capabilities, innovative thinking, and complex problem-solving skills[5]. These advancements establish a solid foundation for cultivating high-quality applied professionals who meet modern mechanical industry demands.

2. The core connotation of OBE concept and the overall idea of reform

The OBE philosophy adheres to the principle of "reverse design and forward implementation". The term "reverse design" refers to a process where educators first define the competency objectives (graduation requirements) students should achieve upon graduation. Based on these objectives, they then design the curriculum system, determine the specific teaching tasks and goals each course should fulfill, and finally organize the instructional content and methods accordingly.

Based on this, the overall reform approach of this course is as follows: Starting from professional graduation requirements to clarify specific learning outcomes; using comprehensive projects as carriers to reconstruct teaching content; adopting student-centered diversified teaching methods such as case-based instruction; aiming for continuous improvement by establishing an assessment mechanism combining formative and summative evaluations. The entire reform process forms a closed-loop system, ensuring that course objectives support graduation requirements while achieving sustained improvement in teaching quality through evaluation feedback.

3. Curriculum teaching reform strategy based on OBE concept

3.1. Reverse design, clear measurable course learning outcomes (CLOs)

In the curriculum design process, we strictly adhere to engineering education accreditation standards. Through in-depth analysis, we identified core competency indicators for this course, including the application of engineering knowledge, problem analysis skills, design and development capabilities, and research competencies. These key metrics encompass practical engineering competencies such as "design and development solutions", logical thinking abilities like "problem analysis", and technical application skills involving "use of modern tools". Building on these foundations, we refined the indicators by transforming these macro-level cognitive frameworks into specific learning objectives tailored to our course. Employing scientific instructional design methodologies, we developed measurable, quantifiable, and measurable CLOs that ensure each learning outcome is clearly described with action verbs and supported by actionable evaluation criteria.

CLO1 (Engineering Knowledge): Students will systematically demonstrate the functional characteristics, detailed structural composition, and key design principles of typical mechanical equipment such as machine tool spindles and gear reducers. Specifically, functional analysis will thoroughly examine the working mechanisms and performance metrics of various mechanical systems; structural analysis will meticulously explain component assembly relationships and fit requirements; while the design principles section emphasizes core concepts including strength calculations, stiffness verification, and reliability design. Through a combination of theoretical instruction and case studies, students will acquire comprehensive knowledge covering the entire process from functional requirement analysis to structural design implementation in mechanical engineering.

CLO2 (Problem Analysis): Possessing a solid foundation in engineering theories such as material mechanics and theoretical mechanics, this capability enables systematic application of professional knowledge to conduct in-depth analysis of critical components in mechanical equipment (e.g., drive shafts, gear pairs, rolling bearings, etc.). Specifically, it involves precise calculation and evaluation of stress states under specific working conditions (including static loads, dynamic loads, alternating loads, etc.), while accurately identifying various potential failure modes (such as fatigue fractures, plastic deformation, wear, etc.). Furthermore, it requires comprehensive identification and assessment of key factors affecting component load-bearing capacity, including but not limited to material performance parameters (e.g., ultimate strength, elastic modulus), structural geometric features (e.g., stress concentration coefficients), surface treatment processes, and operating environmental conditions.

CLO3 (Design/Development Solutions): The students are expected to be capable of independently completing structural design solutions for simple mechanical equipment (such as small belt conveyor transmission systems and single-stage gear reducers) based on specific operational performance requirements (e.g., power transmission capacity, speed range, working environmental conditions), while strictly adhering to national mechanical design specifications and industry standards. During the design process, this involves rationally determining transmission system configurations, selecting appropriate drive mechanisms, conducting detailed parameter calculations and strength verification for key components (e.g., shafts, gears, bearings, couplings), and ultimately achieving optimal component selection and matching. Additionally, comprehensive consideration is given to maneuverability, assembly feasibility, and maintenance convenience to ensure that the design solution not only meets performance requirements but also demonstrates cost-effectiveness and reliability.

CLO4 (Using Modern Tools): The students are expected to be proficient in at least one mainstream 3D modeling software (e.g., SolidWorks, UG/NX) and capable of independently completing 3D modeling, parametric design, and assembly simulation for mechanical equipment components, with expertise in complex structural modeling. Also they need to be competent in engineering drawing software (e.g., AutoCAD), able to accurately create part drawings and assembly diagrams according to national mechanical drafting standards (GB/T), including technical details such as dimensional tolerances and form/position tolerances. And they are expected to be capable of conducting static performance simulation analysis on key components using finite element analysis software (e.g., ANSYS, ABAQUS), including establishing reasonable finite element models, setting boundary conditions, analyzing stress-strain distribution, and providing preliminary engineering judgments and optimization recommendations.

CLO5 (Innovation and Multi-Constraint Coordination): The students are expected to be capable of systematically integrating multiple constraints in complex engineering design, including lightweight design, structural reliability, cost control, production feasibility, and environmental protection requirements. By establishing a multidimensional evaluation system, students learn to conduct comparative analyses of different design solutions and apply innovative thinking to continuously optimize them. Throughout this process, they demonstrate the ability to balance engineering constraints and break through conventional limitations, ultimately developing designs that meet all requirements while showcasing innovative value.

CLO6 (Team Collaboration and Communication): Through in-class group assignments, team members develop the ability to collaborate effectively on shared project themes. By establishing robust communication mechanisms, they maintain close coordination to ensure timely and accurate information exchange, thereby facilitating smooth achievement of phased project objectives. In professional presentation, participants not only master solid technical knowledge but also demonstrate excellent technical documentation skills. They produce logically structured technical reports and standardized documents that meet project requirements, ensuring precise technical details while achieving professional presentation of project outcomes. This provides reliable technical support for team decision-making and subsequent work. Additionally, proficiency in using charts, data visualization, and other auxiliary tools enhance the clarity of complex technical content, significantly improving the efficiency and effectiveness of technical communication.

3.2. Restructuring teaching content: modular integration with project as carrier

To completely abandon the traditional textbook teaching model that mechanically lists knowledge by chapters, this course innovatively employs project-driven pedagogy. It selects comprehensive projects rich in engineering practice significance, such as "Structural Design of a Certain Vertical Machining Center Spindle Box" or "Structural Design of High-Speed Handling Robot Arm", and systematically reorganizes the entire semester's teaching content into four progressive instructional modules:

Fundamental Theory Module: This module focuses on essential engineering mechanics principles for mechanical structure design, the performance characteristics and selection criteria of common engineering materials, methods for determining mechanical precision design and tolerance specifications, as well as machining process requirements. Through systematic theoretical instruction, it equips students with a solid theoretical foundation to advance their practical project design capabilities.

Modern Design Methodology Module: This module keeps pace with contemporary trends by incorporating cutting-edge mechanical design theories and methodologies such as finite element analysis (FEA), optimization design, and reliability design. Through hands-on practical training sessions, we provide students with expert guidance to master the operation of mainstream engineering analysis software like ANSYS and SolidWorks Simulation. We emphasize integrating these modern design approaches directly into critical component analysis and optimization practices within actual projects.

Typical Component Design Module: This module is closely aligned with practical project requirements, providing systematic and in-depth explanations of design principles, processes, and calculation methods for key mechanical components such as spindle systems, transmission systems, support parts, and connectors. Through analysis of abundant engineering case studies, students can better grasp the core design concepts and practical experience of various mechanical components.

Integrated and Innovative Module: Building upon the foundation of the first three modules, we guide students to organically integrate theoretical knowledge, modern design methodologies, and practical experience in component design. This enables them to successfully complete the entire design process, including comprehensive project planning, detailed structural analysis, engineering drawing preparation, and technical documentation. Furthermore, we actively encourage students to innovate and optimize their designs while meeting requirements, thereby cultivating their engineering innovation awareness and practical capabilities.

This modular design integrates theoretical knowledge with practical project tasks, ensuring a seamless connection between learning content and real-world practice. Within this framework, learners not only systematically acquire professional expertise but also apply their skills in authentic project environments, creating a virtuous cycle of "learning by doing and doing by learning". This two-way interactive approach deepens understanding of theoretical concepts while enhancing practical application capabilities, significantly improving overall learning outcomes.

3.3. Innovative teaching methods: online and offline hybrid, student-centered

This course innovatively integrates three components: "Online MOOC/SPOC, offline flipped classrooms, and project-based learning" forming a blended teaching system. Through carefully designed instructional modules that leverage the complementary strengths of online and offline approaches, it maximizes synergies between digital pedagogy and traditional classroom methods to enhance teaching quality and learning outcomes. For the online module (primarily responsible for systematic delivery of foundational theoretical knowledge), we have restructured core self-directed learning materials into 10-15 minute micro-lectures based on cognitive principles and learning patterns. Each video features detailed knowledge maps and study guides, uploaded to leading platforms Yiwang Learning Platform and Chaoxing Learning Platform. Students can flexibly manage their pre-class preparation schedules according to individual learning styles and comprehension levels. The platform provides intelligent online quizzes to assess learning progress while featuring interactive discussion forums that facilitate teacher-student and peer-to-peer exchanges. Through data analytics, instructors gain comprehensive insights into key metrics including video viewing duration, quiz scores, and discussion participation levels, enabling precise learning tracking and personalized guidance. In offline teaching (focusing on deep cultivation of knowledge application and capability enhancement), we implemented revolutionary educational reforms: Classroom activities were meticulously designed into four progressive modules. First is the project seminar module, where learning groups present phased outcomes according to project schedules, with teachers and students collaboratively addressing technical bottlenecks through brainstorming for innovative solutions. Next is the case study module, where instructors focus on core curriculum challenges by selecting typical engineering cases for multidimensional analysis, helping students build comprehensive knowledge frameworks and engineering thinking. Third is the software workshop module, where students use engineering software like FEA and CAD in specialized labs, systematically enhancing digital design capabilities and practical engineering skills through simulated real-world project workflows. Finally, the project review module involves regular mid-term evaluations and final defense sessions, where interdisciplinary faculty teams assess project outcomes from dimensions including innovation, completion quality, and technical sophistication while providing professional development guidance. This teaching model has successfully achieved three key transformations: shifting traditional one-way knowledge transmission classrooms into interactive learning communities; transforming passive learning into active exploration processes; and expanding teachers' roles from solo lecturers to multifaceted mentors offering project guidance, resource coordination, and learning facilitation, ultimately establishing a student-centered new teaching paradigm.

3.4. Building a diversified assessment and evaluation system: focusing on process, continuous improvement

To fundamentally reform the traditional "one exam determines grades" evaluation model, teachers need to establish a comprehensive assessment system that spans the entire teaching cycle and incorporates multi-dimensional indicators. The essence of this system is the implementation of direct and objective evaluations of CLOs for each subject, as depicted in Table 1.

By establishing this scientific and comprehensive evaluation mechanism, teachers can systematically assess the achievement of course learning objectives from multiple dimensions including knowledge mastery, skill development, and quality enhancement. During the evaluation process, educators should not only focus on students' exam scores but also collect feedback data through various channels such as self-assessment, peer reviews, and expert evaluations to ensure the comprehensiveness and objectivity of the assessment results. At the end of each teaching cycle (typically a semester), the course teaching team conducts in-depth statistical analysis and data mining of all assessment metrics. Through scientific quantitative indicators, they accurately identify weak links in the teaching process. For instance, when statistics show that over 60% of students scored below 70 points in the Finite Element Analysis (FEA) report project, this clearly indicates that the teaching effectiveness of the "Modern Design Methods Module" has fallen short of expectations. These empirical data-driven analyses provide precise improvement directions for optimizing subsequent teaching plans, including content adjustments, methodological enhancements, and resource optimization. Through this closed-loop quality improvement mechanism of "scientific evaluation-multidimensional feedback-continuous improvement," teachers can continuously refine teaching processes, enhance instructional quality, and ultimately achieve steady progress in talent cultivation standards.

Table 1: The objective evaluations of CLOs for the course.

Evaluation dimension	Evaluation content and method	Supporting CLO	Weight
Process evaluation (50%)	Online quizzes, classroom questions, discussion participation	CLO1	10%
	Periodic assignments (such as mechanical calculation book, FEA analysis report)	CLO2	25%
	Mid-term project review (plan review, team contribution)	CLO3, CLO4, CLO5, CLO6	15%
Summative assessment (50%)	Final project results: engineering drawings, design specifications, 3D models	CLO3, CLO4	30%
	Final defense: personal statement, answer questions	CLO5, CLO6	20%

4. Curriculum teaching reform strategy based on OBE concept

After the implementation of teaching reform based on OBE concept, the mechanical equipment structural design course will achieve significant improvement in many aspects, which is reflected in the following aspects:

Firstly, in terms of cultivating students' capabilities, we have restructured the curriculum system centered on "mechanical structure design—strength analysis—optimal integration" while enhancing practical training in CAD/CAE software, design and verification of typical components, and comprehensive lightweighting practices. This systematic approach aims to develop students' engineering competencies. The program also provides specialized training in professional software like ANSYS and SolidWorks, stimulating innovative thinking through project-based teaching. By collaborating in actual equipment structure design tasks, students 'comprehensive professional skills are comprehensively enhanced, enabling them to better adapt to industry trends and meet enterprises' specific demands for mechanical design professionals.

Secondly, regarding the transformation of teachers' roles, the teachers are evolving from traditional knowledge transmitters to facilitators and motivators in the learning process. This shift is not only reflected in innovative classroom teaching methods but also demonstrated through strategies like case-based instruction on typical mechanical structures, heuristic discussions on structural optimization, and project guidance. These approaches effectively stimulate students' learning initiative and enhance their ability to solve real-world engineering problems. Meanwhile, through continuous interaction with students, teachers continuously reflect on and refine their teaching content and methods, achieving mutual growth between teaching and learning.

Finally, in terms of continuous improvement of course quality, we establish a big data-driven evaluation system to comprehensively collect and scientifically assess students' learning outcomes—including drawing quality, calculation reports, simulation results, and project completion rates—as well as teaching process data. This data-driven quality assurance mechanism will propel the structural design of mechanical equipment curriculum into a virtuous cycle of "evaluation-improvement-enhancement", ultimately achieving sustained enhancement of students' design capabilities and engineering application competencies.

5. Conclusions

In conclusion, the systematic teaching reform and practical exploration of the "Mechanical Equipment Structural Design" course based on the OBE philosophy can effectively address prominent issues in traditional teaching methods, such as overemphasis on knowledge at the expense of skills, theoretical knowledge over practical application, and results over process. By scientifically setting quantifiable learning objectives, reconstructing teaching content through engineering projects, innovating blended online-offline teaching models, and establishing a diversified evaluation system combining formative and summative assessments, this approach truly implements the modern educational concept of "student-centered development." It holds significant theoretical value and practical guidance significance for cultivating high-quality new engineering mechanical talents with solid professional foundations, outstanding engineering practice capabilities, and innovative thinking.

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