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Project Case-Driven Teaching Reform and Practice of the Course Mechanical Optimization Design

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Abstract: To address the insufficient integration between theoretical instruction and engineering practice and the limited abilities of graduate students in engineering problem analysis and optimization modeling in the course Mechanical Optimization Design, a project case-driven teaching model is developed. The course content is reorganized according to the complete process of mechanical optimization design, integrating engineering problem analysis, optimization model development, algorithm selection, computational implementation, and design evaluation. A progressive case system consisting of basic and comprehensive cases is established, enabling students to gradually progress from theoretical understanding and algorithm training to engineering problem formulation and independent optimization modeling. Project tasks are implemented in stages, and a diversified assessment system combining theoretical knowledge, project processes, and project outcomes is adopted to evaluate students' optimization modeling, computational tool application, engineering analysis, teamwork, and technical communication abilities. The proposed teaching model provides a practical framework for integrating optimization theory with engineering practice and cultivating graduate students' ability to analyze and solve complex engineering problems using optimization methods.

1. Introduction

With the development of intelligent manufacturing, high-end equipment, and digital design technologies, modern mechanical product design has increasingly become characterized by multiple variables, multiple objectives, multiple constraints, and multidisciplinary coupling [1,2]. These developments place higher demands on mechanical engineering professionals in terms of optimization modeling, computational analysis, and design evaluation. Mechanical Optimization Design is an important graduate-level course in mechanical engineering and serves as a vital link between mechanical design theory, numerical methods, and engineering practice.

Traditional teaching is generally organized around optimization models, mathematical foundations, optimization algorithms, and numerical examples, with an emphasis on algorithmic principles, formula derivation, and program implementation. Although this approach helps students systematically master the theories and methods of optimization design, most textbook cases are simplified mathematical models in which the design variables, objective functions, and constraints have already been specified [3]. Consequently, students receive insufficient training in identifying optimization problems, extracting key parameters, and developing optimization models from actual mechanical products, which may result in the problem of being "able to calculate but unable to model."

In addition, some students tend to directly use optimization functions in MATLAB, Python, or other software when solving practical problems, without fully understanding the applicable conditions and engineering limitations of different algorithms. When numerical non-convergence, boundary solutions, or unreasonable optimization results occur, they often find it difficult to identify the causes from the perspectives of model assumptions, variable ranges, and constraint settings. Traditional course assessment is also mainly based on final examinations and assignments, making it difficult to comprehensively evaluate students' abilities in engineering problem analysis, software application, teamwork, and technical communication [4]. Therefore, diversified assessment methods that integrate learning processes and project outcomes are needed to better evaluate students' comprehensive engineering abilities [5].

Project case-driven teaching uses actual or realistic engineering projects as instructional carriers and integrates problem analysis, model development, algorithm selection, numerical solution, and design evaluation throughout the teaching process. This approach helps transform abstract optimization theories into practical engineering applications. Therefore, this study focuses on the graduate course Mechanical Optimization Design and carries out teaching reform in terms of teaching objectives, course content, case system, implementation process, and assessment methods, thereby establishing a project case-driven teaching model oriented toward the cultivation of students' engineering practice abilities.

2. Project Case-Driven Teaching Reform

2.1 Clarifying the Course Objectives

The teaching reform takes the cultivation of engineering practice ability as its core objective. On the basis of students' mastery of the fundamental theories and commonly used algorithms of optimization design, the course focuses on developing the following five abilities.

(1) **Engineering problem analysis.** Students should be able to identify the main factors affecting product performance according to the design requirements, structural characteristics, and operating conditions of mechanical products, and clearly define the optimization object and design requirements.

(2) **Optimization model development.** Students should be able to appropriately select design variables, determine objective functions and constraints, and transform practical engineering problems into computable mathematical models.

(3) **Application of computational tools.** Students should be able to use MATLAB, Python, and finite element analysis software to conduct parameter analysis, simulation, and optimization.

(4) **Engineering solution evaluation.** Students should be able to evaluate optimization results in terms of structural performance, manufacturability, operating conditions, and economic efficiency, and further improve the design according to the evaluation results.

(5) **Teamwork and technical communication.** Students should be able to complete project tasks through group collaboration and clearly present their optimization strategies and design results through project reports, figures, and oral presentations.

2.2 Restructuring the Course Content According to the Optimization Design Process

Traditional courses are generally organized according to different categories of optimization algorithms, which may lead to a separation between algorithmic knowledge and engineering applications. After the reform, the course content is reorganized according to the complete process of mechanical optimization design and divided into five modules: engineering problem analysis, optimization model development, optimization algorithm selection, computational implementation, and result evaluation.

The engineering problem analysis module focuses on identifying design requirements, determining performance indicators, and analyzing influencing factors. The optimization model development module emphasizes the methods for determining design variables, objective functions, constraints, and variable ranges. The optimization algorithm selection module compares the characteristics and applicable conditions of gradient-based algorithms, direct search methods, and intelligent optimization algorithms. The computational implementation module guides students in using MATLAB, Python, or finite element analysis software to conduct parametric analysis and optimization. The result evaluation module focuses on the engineering rationality of optimization results, parameter sensitivity, and the practical feasibility of the proposed design.

Through this restructuring, the teaching emphasis shifts from the isolated instruction of optimization algorithms to comprehensive training covering engineering problem analysis, optimization modeling, numerical solution, and design evaluation, thereby enabling theoretical knowledge and project-based practice to support and reinforce each other.

2.3 Developing a Progressive Project Case System

According to the difficulty of the course content and the development of students' abilities, project cases are divided into basic and comprehensive cases.

Basic cases, such as lightweight shaft design, beam cross-sectional optimization, spring parameter optimization, and gear transmission optimization, are used to explain fundamental concepts and common algorithms. Relatively complete mathematical models are provided to help students understand the relationships among design variables, objective functions, and constraints.

Comprehensive cases focus on complete mechanical products or key components. Three cases are introduced: lightweight optimization of mechanical structures, performance optimization of precision mechanical components, and parameter optimization of mechanical transmission systems. Students independently complete problem analysis, model development, algorithm selection, and result evaluation. Through progressive tasks, they gradually move from solving predefined models to developing optimization models independently.

2.4 Implementing Project-Based Teaching in Stages

The comprehensive project is organized into four stages: problem analysis, model development, optimization, and result evaluation.

(1) **Problem analysis**, students analyze the structural characteristics, performance requirements, and operating conditions of the engineering object according to the project brief. They identify the main influencing factors, preliminarily determine the design variables and optimization objectives, and submit a project analysis form.

(2) **Model development**, students formulate the objective functions, constraints, and variable ranges mathematically. They are also required to explain the model assumptions, parameter sources, and basis for simplification, and then prepare an optimization model description.

(3) **Optimization**, students select appropriate optimization algorithms according to the

characteristics of the problem and perform numerical calculations using MATLAB, Python, or finite element analysis software. They also compare the effects of different parameter settings or algorithms on the optimization results.

(4) **Result evaluation**, students compare product performance before and after optimization, analyze the relationships among the design variables, objective functions, and constraints, and evaluate the rationality of the proposed design in terms of structural performance, manufacturability, operating requirements, and cost.

Specific deliverables are required at each stage, including the project analysis form, model description, program code, interim presentation, and final report. Through stage-by-stage reviews, the instructor can promptly identify problems in variable selection, model development, and program implementation. This approach prevents students from completing all project tasks only at the end of the course and improves the continuity and effectiveness of the teaching process.

2.5 Integrating Group Collaboration with Engineering Evaluation

Course projects are completed in groups of three to five students. Group members may undertake different tasks, including data collection, model development, programming, simulation, and result analysis, while each student is required to understand the complete project process. Individual work records and random oral questioning are used to evaluate personal participation and prevent unequal contribution.

Engineering evaluation is also emphasized throughout the project. Students are required to examine whether the design variables reach their bounds, whether the constraints are satisfied, and whether the optimized design is feasible for manufacturing and operation. When unreasonable results occur, they must identify possible deficiencies in the variable ranges, constraints, or objective functions and revise the model accordingly. Through the iterative process of "calculation–analysis–revision–recalculation," students develop teamwork skills, individual responsibility, and the ability to evaluate optimization results from an engineering perspective.

3. Course Assessment and Evaluation

The course adopts a diversified assessment system that combines theoretical knowledge, project implementation, and project outcomes, with particular emphasis on students' engineering practice and comprehensive application abilities.

Theoretical knowledge assessment accounts for 30% of the final grade. It mainly evaluates students' mastery of the fundamental concepts, mathematical models, and commonly used algorithms of optimization design.

Project process assessment accounts for 30% of the final grade. It includes classroom discussions, project analysis forms, model descriptions, interim reviews, programming records, and individual contributions, with an emphasis on students' participation and their abilities to analyze and solve problems throughout the project.

Project outcome assessment accounts for 40% of the final grade. It mainly covers the final report, the rationality of the optimization model, the correctness of computational results, engineering design analysis, and project presentation and defense. The components and proportions of the course assessment are shown in Table 1.

The final value of the objective function is not treated as the sole criterion for project evaluation. Greater attention is given to whether students can accurately identify engineering problems, establish appropriate optimization models, select suitable algorithms, interpret optimization results, and propose effective improvements. By combining process-oriented and outcome-oriented evaluation, the assessment system provides a comprehensive measure of students' knowledge mastery, engineering modeling, software application, teamwork, and technical communication abilities.

Table 1: Course assessment components and proportions

Assessment components	Contents	Proportions
Theoretical knowledge	Basic concepts of optimization design, mathematical models, and common optimization algorithms.	30%
Project process evaluation	Project analysis, optimization model development, algorithm selection, programming implementation, classroom discussion, interim review, and individual contribution.	30%
Project outcome evaluation	Final project report, optimization results, engineering feasibility analysis, design evaluation, and oral presentation	40%

4. Effects of the Teaching Reform

Project case-driven teaching strengthens the connection between course theory and mechanical engineering practice. Students gradually shift from passively accepting predefined optimization models to actively analyzing engineering requirements, identifying key parameters, and developing optimization models. As a result, they place greater emphasis on the rationale for selecting design variables, objective functions, and constraints.

During project implementation, students are required to integrate knowledge from mechanical design, engineering mechanics, finite element analysis, and programming. They also use MATLAB, Python, or finite element analysis software to conduct parametric analysis and optimization, which promotes the integrated application of multidisciplinary knowledge and improves their ability to use computational tools.

Through comparisons of design performance before and after optimization, result analysis, and classroom presentations, students gradually recognize that a mathematically optimal solution is not necessarily the most appropriate engineering solution. They become better able to evaluate design results in terms of structural performance, manufacturing processes, and operating conditions, thereby strengthening their engineering analysis and design decision-making abilities.

In addition, comprehensive projects can be integrated with the instructor's research projects and students' research interests. In this way, course projects provide a foundation for graduate research training and promote effective connections among course learning, research practice, and thesis work.

5. Conclusions

To cultivate graduate students' engineering practice abilities, this study develops a project case-driven teaching model for the course Mechanical Optimization Design. The course content is reorganized according to the optimization design process, progressive basic and comprehensive cases are developed, project-based teaching is implemented in stages, and an assessment mechanism combining process-oriented and outcome-oriented evaluation is established. In this way, optimization theory, computational methods, and mechanical engineering practice are integrated throughout the teaching process.

The proposed teaching model helps address the limitations of traditional teaching, which often emphasizes algorithm instruction over engineering modeling and computational results over design evaluation. It improves students' abilities in engineering problem analysis, optimization model development, computational tool application, and design evaluation. Future work will further enrich the project case database, incorporate additional research and industry-based engineering projects, and continuously improve the course content and teaching methods through the analysis of teaching data, thereby enhancing the overall quality of the course.

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References

[1] Ebrahimi B, Bataleblu A, Roshanian J. (2024) Developing an intelligent systems design framework based on multidisciplinary design analysis and multi-agent thinking integration. Expert Systems with Applications, 248: 123363.
[2] Jing D. (2025) A Comparative Study of Mechanical Engineering Talent Training Models under the OBE Concept in Chinese and UK Universities and Its Implications. Curriculum and Teaching Methodology, 8(6): 153-157.
[3] Qian L, Wang H, Zhang Y. (2025) Teaching reform strategies of "Mechanical Equipment Structural Design" course based on OBE concept. Curriculum and Teaching Methodology, 8(7): 35-40.
[4] Paloposki T, Virtanen V, Clavert M. (2025) From a Final Exam to Continuous Assessment on a Large Bachelor Level Engineering Course. European Journal of Engineering Education, 50(1): 164-177.
[5] Hernández-Campos M, Prado-Calderón J E, Gonzalez-Torres A, García-Peñalvo F J. (2025) Direct measurement of learning outcomes in higher education: A proposal of nine standardized scales for continuous improvement in engineering programs. Eval Program Plann, 112: 102638.