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Strategies and Implementation of "Modern Design Methods" Teaching Reform in the Context of Engineering Practice.

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Abstract

The purpose of this article is to delve into the integration of the "Modern Design Methods" curriculum within the graduate mechanical engineering program and to deliberate on the strategies for its pedagogical reform. Firstly, this paper analyzed the existing teaching syllabus, pointed out the correlation between teaching content and engineering practice, and the matching degree between teaching methods and students 'ability cultivation. Then, the teaching strategies for engineering practice were put forward, including the selection and integration of engineering cases, interdisciplinary project design, and industry cooperation. The paper also discussed the innovation of teaching methods, such as inverted classroom, online learning platform application, and established a teaching feedback mechanism. Through quantitative evaluation and case analysis, the effectiveness of teaching reform was summarized, and suggestions for future teaching were put forward, including continuous updating of teaching content, strengthening interdisciplinary learning, strengthening practical links and promoting teacher-student interaction. Finally, this paper emphasized the sustainability and development direction of teaching reform, and the importance of establishing an open teaching environment.

Keywords

Modern design methodology, Engineering practice teaching, Teaching evaluation, Teaching reform strategy.

1. Introduction

"Modern Design Methods" plays an essential role as a core course in the graduate education of mechanical engineering programs. It not only provides students with basic knowledge of product design, but also covers modern design techniques and methods such as optimal design, reliability design, and finite element method, which are key components of mechanical system design principles [1-2]. Through the study of this course, students are able to master the ability to use modern tools for efficient design, which is crucial for their future professional development in the field of mechanical engineering.

In the context of globalization and the rapid development of science and technology, design education in the field of mechanical engineering is facing the challenge of keeping pace with the evolving demands of industry. The teaching content and methods of "Modern Design Methods" urgently need innovation to meet the rapidly changing needs of engineering practice. For instance, Sun Jingmin and others have emphasized the importance of modern design methods in improving design efficiency and quality in their publications. Additionally, research by Zhang E and others has shown that modern design theories and methods play a significant role in fostering students' innovative thinking and their ability to solve complex engineering problems[3]. These studies highlight the necessity for teaching reform and the integration of

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modern design methods with real-world engineering problems in the teaching model. Qiao Jianyong and others have proposed constructing a student-centered teaching organization model and a "three-through" teaching reform oriented towards the new engineering, providing a new perspective for the teaching reform of "Modern Design Methods"[4]. Qin Wenjie and Cheng Ying, in their work on modern design methods, have proposed teaching strategies that combine theory with practice, which helps students better understand and apply design methods[5]. To further enhance teaching effectiveness, Elsayed A. Elsayed and Yang Zhou, in their work on reliability engineering, have proposed teaching strategies that combine theory with practice, aiding students in better understanding and applying design methods. The improvement of this teaching method aims to cultivate students' systematic thinking and innovative design capabilities, laying a solid foundation for their ability to solve systems problems in practical work within the fields of mechanical engineering and automation.

In summary, the importance of "Modern Design Methods" is self-evident. It is not only related to the enhancement of students' professional skills but also to the implementation of the national innovation-driven development strategy. By continuously updating teaching content and methods, we can cultivate more mechanically engineering graduate students with international competitiveness, contributing to the country's scientific progress and industrial development.

2. Review of Existing Syllabus

The existing syllabus for "Modern Design Methods" reflects comprehensive requirements for graduate education in mechanical engineering, covering multiple aspects from fundamental theories to advanced applications. The course content is designed to cultivate students' comprehensive design capabilities, including key technologies such as optimization design, reliability design, and finite element methods. However, reviews indicate that despite the richness of the course content, there is still room for improvement to meet the demands of modern education. For instance, the course may require more case studies and practical sessions to enhance students' hands-on abilities. The close integration of teaching content with mechanical engineering practice is key to the success of the "Modern Design Methods" course. The current syllabus already includes several practice-related aspects, such as simulating real engineering problems through case analyses and project work. Nevertheless, analysis suggests that further incorporation of industry collaboration projects, allowing students to participate directly in industrial design, could better facilitate the understanding of the combination of theory and practice [2,6-7].

The diversity and innovation of teaching methods are crucial for the development of students' abilities. The current syllabus employs a combination of lectures and discussions, which aids in students' comprehension and absorption of knowledge. However, assessments reveal that teaching methods can be further innovated by adopting approaches such as flipped classrooms, group collaborative learning, and online interactive platforms to increase student engagement and autonomous learning capabilities. Additionally, incorporating interactive elements like design competitions and simulation projects can better stimulate students' innovative thinking and their ability to solve complex problems.

3. Teaching Objectives and Student Needs

The course "Modern Design Methods" aims to cultivate students' professional knowledge and skills, particularly in areas such as optimization design, reliability design, and finite element methods. Through the assessment of the curriculum implementation and student performance, it has been observed that students have made certain progress in mastering theoretical knowledge. However, the analysis also indicates that there is still a gap in applying theoretical

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knowledge to practical engineering problems, which may be due to a lack of sufficient practical opportunities and case analyses [8-9].

The course's ideological and political education objectives are to foster a sense of social responsibility and ethical values among students, while the quality goals focus on their creativity, collaboration, and sustainability. To achieve these objectives, the course needs to design activities that integrate political education with professional skill training, such as team projects, social practice, and ethical case discussions. Such integration helps students develop the correct values and a sense of social responsibility alongside their professional growth [8-9].

Student feedback is an essential pathway for evaluating and improving teaching effectiveness. Through surveys, interviews, and course evaluations, opinions on course content and teaching methods are collected. Students generally believe that the course content is rich and highly professional, but there is room for improvement, especially in increasing interactivity, practicality, and case analysis. Additionally, students welcome the diversity of teaching methods but also expect more personalized guidance and support from instructors [9-11].

4. The Reform of Teaching Content and Method

Optimization design methods are one of the core components in the field of mechanical design, and their teaching improvements should focus on the integration of theory and practice. By introducing the latest optimization algorithms and software tools, the efficiency and accuracy with which students solve real-world engineering problems can be enhanced. A case-driven approach in teaching allows students to grasp the basic principles and application skills of optimization design while solving specific problems. Additionally, encouraging students to participate in scientific research projects deepens their understanding and application of optimization design methods through hands-on operations.

Reliability design and finite element methods are important tools for evaluating and ensuring the quality of product design. The application of case teaching in this area can be achieved by selecting cases closely related to the industry, allowing students to deeply understand the importance and application process of these methods through analysis and problem-solving. The selection of cases should cover a variety of engineering backgrounds to enhance students' adaptability and innovative thinking. Moreover, through hands-on operation with simulation software, students can quickly master the skills of finite element analysis and understand its role in reliability design.

Reverse engineering design and dynamic design methods are important means to solve complex problems in mechanical design. In teaching, project-driven approaches can be used to involve students in real engineering cases, thereby improving their practical and innovative abilities. For instance, by collaborating with enterprises, students can directly face the design challenges of industrial products and use reverse engineering techniques to improve product design. At the same time, the teaching of dynamic design methods should be combined with modern simulation technology, allowing students to understand design principles through simulation experiments, enhancing the effectiveness and safety of the design.

5. Course Case Base

Incorporating specific engineering application cases in the "Modern Design Methods" course can enhance students' understanding and application of theoretical knowledge. Here are several method cases that can be applied to the course:

5.1. Optimization Design Method Cases:

(1) Genetic Algorithm (GA) Case:

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Background: Design the optimal motion path for a mechanical arm to minimize energy consumption and time. Teaching Application: Students can use genetic algorithms to simulate the motion of the mechanical arm, define a fitness function (such as a weighted sum of energy consumption and time), and utilize the iterative search capability of genetic algorithms to find the optimal solution.

(2) Particle Swarm Optimization (PSO) Case:

Background: Optimize the aerodynamic shape of a car to reduce the drag coefficient. Teaching Application: Students can use particle swarm optimization algorithms, define the design variables of the aerodynamic shape, and use the drag coefficient as a fitness function for multi-generational evolutionary calculations to obtain the optimal aerodynamic design.

(3) Multi-Objective Optimization Case:

Background: Design a mechanical structure that maximizes strength while minimizing weight. Teaching Application: By introducing the concept of multi-objective optimization, students can learn how to balance two or more often conflicting design objectives and use methods such as Pareto optimality to find the best solution.

(4) Response Surface Methodology (RSM) Case:

Background: Optimize the parameters in the injection molding process to improve product quality. Teaching Application: Students can use experimental design (DOE) to build a mathematical model between input parameters and output responses, and analyze and optimize these parameters through response surface methodology.

(5) Gradient Descent Method Case:

Background: Optimize the support position of a structure in finite element analysis to minimize maximum displacement. Teaching Application: Students can apply the gradient descent method, calculate the gradient of displacement, and update the support position to gradually approach the design scheme with minimum maximum displacement.

(6) Monte Carlo Simulation Case:

Background: Evaluate the reliability of different design schemes under uncertainty. Teaching Application: Students can use Monte Carlo simulation to generate a large number of random samples, evaluate the performance distribution of design schemes under different input conditions, and thus select the most reliable design.

5.2. Finite Element Analysis Cases:

(1) Structural Stress Analysis Case:

Background: Analyze the stress distribution of a car suspension system. Teaching Application: Students can use finite element software to mesh the geometric model of the suspension system, apply loads and boundary conditions, and calculate and analyze the stress and deformation of the structure under different working conditions.

(2) Thermal Analysis Case:

Background: Simulate the temperature distribution in a heat exchanger. Teaching Application: Through finite element analysis, students can study the impact of different design parameters on heat exchange efficiency, such as flow channel shape, material selection, and fluid velocity.

(3) Fluid Dynamics Analysis Case:

Background: Analyze the airflow and lift around an airplane wing. Teaching Application: Students can use finite element software for computational fluid dynamics (CFD) simulation to study the impact of different wing designs on aerodynamic performance.

(4) Vibration Analysis Case:

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Background: Predict the natural frequency and mode shape of a rotating machine. Teaching Application: Students can use finite element methods for modal analysis to determine the dynamic characteristics of mechanical structures and design dampers to reduce vibration.

(5) Fatigue Analysis Case:

Background: Assess the fatigue life of a reciprocating piston under cyclic loads. Teaching Application: Through finite element methods, students can calculate the stress cycles of the piston and apply fatigue theory to predict its service life.

5.3. Reverse Engineering Cases:

(1) Reverse Analysis of Automotive Engine Components:

Background: Reverse engineer an old-model automotive engine's intake system to design a more efficient one. Teaching Application: Students can obtain geometric data of the components through 3D scanning technology, use reverse engineering software for modeling, and analyze airflow dynamics characteristics.

(2) Geometric Reverse Engineering of Industrial Robot Arms:

Background: Reverse engineer an industrial robot arm to understand its kinematics and dynamics. Teaching Application: Students can use motion capture systems to record the motion of the robot arm, then use reverse engineering methods to analyze its kinematic principles and perform simulation.

(3) Functional Reverse Engineering of Medical Devices:

Background: Reverse engineer a medical device (such as a heart valve) to improve its design for better biocompatibility and performance. Teaching Application: Students can analyze the working principles and functional requirements of medical devices and optimize the design through knowledge of material science and biomechanics.

(4) Interface Reverse Engineering of Consumer Electronics:

Background: Reverse engineer the user interface of a consumer electronics product (such as a smartphone) to design a more ergonomic operation interface. Teaching Application: Students can understand issues in user experience through user research and interface analysis, and apply reverse engineering principles to propose improvement solutions.

(5) Restoration and Redesign of Antique Machinery:

Background: Reverse engineer an antique machine to restore its damaged parts while maintaining its historical value. Teaching Application: Students can learn how to use modern measurement tools and techniques to replicate and restore parts of antique machinery while maintaining its original design style.

6. Conclusions and Suggestions

The "Modern Design Methods" course has undergone pedagogical reforms to boost the innovation and practical skills of graduate students, aligning with the swift pace of engineering needs and technological evolution. The reforms, which have incorporated case-based teaching, hands-on projects, interactive learning, and technological tools, have yielded significant benefits:

Blending Theory with Practice: Students now have the opportunity to bridge the gap between academic knowledge and practical engineering challenges through case studies and practical projects, which has significantly enhanced their practical skills and innovative thinking.

Variety in Teaching Approaches: A range of teaching methods, from flipped classrooms and group discussions to online learning platforms, has been implemented, leading to increased student participation and autonomous learning.

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Utilization of Technological Tools: The proficiency of students in addressing intricate engineering issues has been elevated through the use of advanced design software and simulation tools, particularly finite element analysis software.

Feedback Mechanisms: Instructors are now better equipped to fine-tune teaching strategies in response to student feedback and course evaluations, ensuring that the educational offerings are tailored to the students' needs and aspirations.

Curriculum Refresh: The curriculum has been enriched with the latest design philosophies and techniques, such as optimization algorithms, reliability design methodologies, and reverse engineering, ensuring that the course content remains at the forefront of the field and highly relevant.

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