Construction and Practice of an Innovative Experimental Teaching Model for Mechanical Design Fundamentals

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Abstract: Against the backdrop of emerging engineering education and first-class course construction, this study addresses the problems in the experimental teaching of Mechanical Design Fundamentals, including time-consuming teacher instruction, inadequate student preview, disconnection between virtual and physical experiments, and monolithic assessment methods. A four-in-one experimental teaching model was developed, consisting of "micro-lecture preview – virtual simulation preview – open practice – diversified assessment." Taking five experimental projects as the carrier, 36 micro-lecture videos were created and integrated into the Xuexitong learning platform. Virtual simulation was employed to realize a "virtual-first, physical-second, virtual-physical complementary" approach. For projects without safety hazards, open laboratory access and flipped classroom strategies were implemented. In addition, a multidimensional process-oriented assessment system was established. Practice shows that this model effectively enhances students' learning interest, autonomous learning ability, and hands-on skills, while improving teacher-student interaction and teaching efficiency. This study provides a practical reference for the reform of mechanical engineering experimental teaching.

Keywords: Mechanical Design Fundamentals; Experimental Teaching Reform; Digital-Intelligent Empowerment; Virtual-Real Integration; Flipped Classroom

1. Introduction

The new generation of information technology is driving the reform of mechanical engineering experimental teaching. Guided by the Ministry of Education's digital education policies, as well as the OBE (Outcome-Based Education) and dual PBL (Problem-Based Learning & Project-Based Learning) concepts, and aligned with the goal of first-class course development, this study explores an optimized teaching model for mechanical design basic experiments. By integrating multiple approaches such as micro-lecture videos, virtual simulation, flipped classrooms, and AI empowerment, this research aims to stimulate students' practical and innovative capabilities, thereby supporting the cultivation of emerging engineering talents with engineering thinking and cross-disciplinary integration abilities.

2. Analysis of Existing Problems in Experimental Teaching of Mechanical Design Fundamentals

The experimental course of Mechanical Design Fundamentals is primarily offered to undergraduate mechanical engineering majors. The current experimental teaching covers projects including gear assembly, comprehensive mechanical transmission, reducer disassembly, bolt connection, etc., totaling 6 class hours. Based on classroom observation and teaching feedback, the following problems and deficiencies have been identified [1-4].

2.1 Solidified Teaching Mode and Insufficient Student Participation

Each experimental project still follows a traditional teaching model, in which teachers explain and demonstrate while students passively receive instructions and operate step by step. There is little space for independent exploration, and thus, low learning initiative. Specific Expressions are as follows:

Before the class of the gear shaping experiment, students are required to complete related theoretical studies and draw according to the given procedures during the class. However, due to a lack of previews and non-standardised operations, the actual completion time far exceeds the allotted 2 class hours, severely disrupting the teaching schedule. The main problems of this experiment are shown in Figure 1.

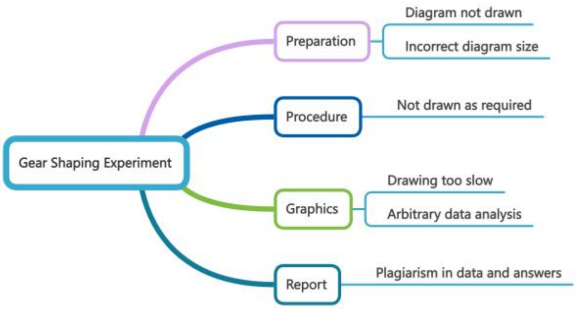

Figure 1. Problems in the Gear Shaping Experiment

In the "Comprehensive Mechanical Transmission Experiment", due to the certain safety risks of self-assembly for transmission devices and the risk of injury to students from bumps or bruises during the assembly process, this experiment has been revised: the instructor will pre-assemble various transmission structures, and students will only obtain experimental data by conducting software tests. However, after the course, some students did not grasp the underlying reasons for the experiment; they were unable to learn how the data were collected and therefore did not understand the essential content of the experiment. The related problems are shown in Figure 2.

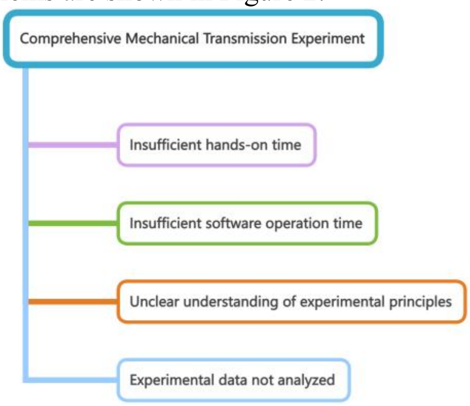

Figure 2. Problems in the Comprehensive Mechanical Transmission Experiment

In the reducer disassembly experiment, the teaching equipment has low precision and lacks lubrication and sealing devices. Therefore, students are only able to gain a basic understanding of the assembly relationship and have not encountered more practical mechanical situations. The relevant problems are illustrated in Figure 3.

Before the experiment of bolt connections, students should be able to learn about the basics of bolt connections and carry out force analysis on bolts themselves. Nevertheless, the follow-up observations after class show that most students are still unfamiliar with the underlying reasons for the experiments. The relevant issues are illustrated in Figure 4.

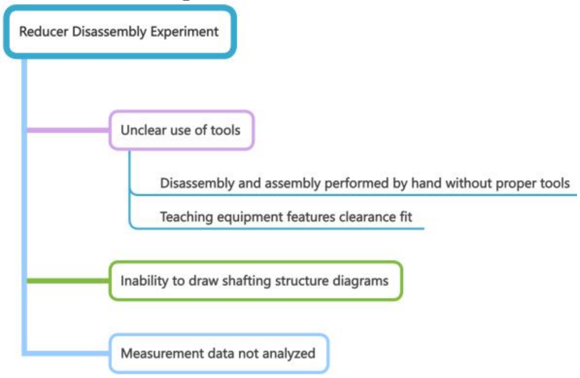

Figure 3. Problems in the Reducer Disassembly Experiment

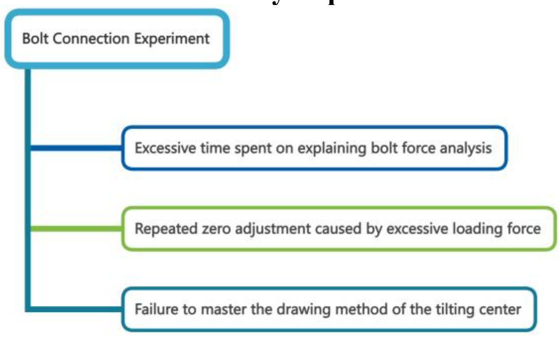

Figure 4. Problems in the Bolt Connection Experiment

2.2 Experimental Conditions are Restricted, and Thus Students Have Fewer Hands-On Opportunities

Due to the dispersed distribution of students' course selections, the experimental sessions are organised in batches and groups under a unified time system to ensure an orderly progress of teaching activities. However, due to a small number of experimental equipment units and limited floor space in some teaching venues, not all students can be accommodated for hands-on operations at the same time. As a result, a considerable number of students cannot gain sufficient practical experience and are thus unable to develop or improve their skills in practical manipulation.

2.3 Most of the Experiments are Verification-Oriented and Lack Cultivation of Innovative Thinking

At present, the experimental curriculum is dominated by verification-type exercises, and design-oriented and all-encompassing projects are conspicuously absent. All the parameters in the experiment were set by the teacher, and the students needed to follow the given instructions precisely. A recipe-like manner does not promote independent exploration or self-study. Therefore, it is not ideal for cultivating students' creative thinking and fails to foster their engineering problem-solving abilities in real-life scenarios.

2.4 Monolithic Assessment System and Low Student Learning Motivation

The way of evaluation is relatively monolithic; only experimental reports are used for assessment, and other all-round qualities of students, such as their operating process and data analysis ability, are neglected. The reports have been graded, but no effective feedback has been provided to inform the students of their deficiencies and deficiencies. In addition, there is little communication among teachers and students before the experiment and after the experiment to provide prompt assistance to students. As a result, the students are unable to learn about the basic ideas of the experiments and what the data mean. At the same time, most students are simply willing to complete the experimental tasks as required and have little interest in learning practical skills or data analysis. Their learning initiative and participation are also low; they are not motivated to think critically or investigate the experimental process further. As a result, the general learning results are far from good.

Therefore, the continuous use of traditional experimental teaching methods has not been able to address the above problems. Given the current conditions of learning and the behaviour of the students, pedagogical reforms should be implemented that are tailored to the actual learning situation of these students. The reform should be based on all-around data of students' academic results, participation and feedback, etc., and then implemented flexibly and reasonably.

3. Design and Production of Micro-Lecture Videos Integrated into the Xuexitong Platform

In response to the problems identified in the experimental teaching mentioned above, this paper puts forward optimisation strategies in terms of teaching resource development, teaching mode reform and instructional innovation [5].

3.1 Design and Production of Micro-Lecture Videos for the Xuexitong Platform

To overcome the limitations of time and space in traditional experimental teaching, a series of micro-lecture videos was designed and produced in this study, and then integrated into the Xuexitong platform to form a blended experimental teaching model combining online and offline methods. This model hopes to motivate students' interest in learning, enhance their hands-on skills, and nurture a spirit of engineering innovation through organised application of digital teaching resources. The special provisions are as follows:

First, a new basic experimental project - the mechanism assembly and mapping experiment - has been added. This project is relatively all-encompassing and design-oriented; thus, students need to independently select and assemble mechanisms, and then map them according to the specified motion requirements. Thus, students can apply what they have learned in class to actual engineering work and develop good habits of learning by doing.

Second, a series of micro-lecture videos were systematically designed and produced to cover all parts of experimental teaching, including experimental preparation, principle explanation, operational procedures, data analysis methods and virtual simulation operations. All video resources have been uploaded to the Xuexitong platform, and students can engage in independent study before, during and after class, as well as review and consolidation of their learning at any time.

Third, continuous optimisation and iteration of micro-lecture resources are being carried out. After releasing the micro-lecture videos, their actual impact on students' learning will be regularly verified by observing students' behavior in class and gathering feedback via the Xuexitong platform. Therefore, the content of the videos and ways of presenting them and teaching methods are constantly being improved to meet the actual learning needs of the students. The particular contents of the micro-lecture production are shown in Table 1.

Table 1. Micro-Lecture Production Details for Experimental Teaching

Video Title	Duration
Introduction to gear machining	26”
Demonstration of generating cutting method	23”
Experimental preparation	34”

Completed drawing of the experiment	10”
Machining principle	25”
Structure of the gear shaping apparatus	35”
Machining principle of the shaping apparatus	45”
Experimental procedures	1’29”
Virtual simulation procedures	50”
Dimensional changes of modified gears	30”
Duration of micro-lectures for Experiment 1	6'07"
Teaching objectives	34”
Experimental principles	1’04”
Experimental procedures	1’23”
Virtual simulation procedures	2’43”
Experimental data analysis	1’24”
Duration of micro-lectures for Experiment 2	7’08”
Virtual simulation of different reducer types	1’10”
Experimental principles	36”
Experimental procedures	1’05”
Virtual simulation procedures	2’01”
Duration of micro-lectures for Experiment 3	4’52”
Force analysis of bolted connections	2’22”
Experimental equipment	34”
Experimental principles	1’12”
Experimental procedures	1’36”
Virtual simulation procedures	1’14”
Experimental data analysis	17”
Duration of micro-lectures for Experiment 4	7’15”
Demonstration of higher-pair and lower-pair assembly (shortest 8')	3’38”
Virtual simulation demonstration	3’50”
Duration of micro-lectures for Experiment 5	7’28”
Total duration	32’52”

As shown in the table above, the length of the micro-lecture videos is as long as 3 minutes and 50 seconds and as short as 8 seconds. A total of 36 task points have been set up, and the total time is 32 minutes and 52 seconds. The Distribution of task points for the experimental projects is reasonable. The short micro-lecture videos are organised well and clearly present the knowledge points for students to learn easily. In addition, all the videos can be watched repeatedly to boost students' enthusiasm for learning and help them study independently by repeatedly viewing and practising.

3.2 Opening Selected Laboratories and Adopting Flipped Classroom Methodology

Due to the limitations of laboratory equipment and student concentration at the same time, some selected laboratories that do not pose a safety risk have been prepared for students to conduct self-study experiments. Thus, the problem of equipment scarcity and scheduling clashes will be alleviated, providing support for the introduction of flipped classroom teaching. In this system, students will be more active in their own study and hands-on exploration, and teachers will stop lecturing and start offering individualised help or support when students need it. Therefore, teacher-student communication has improved, student participation has increased, and an inner desire to learn has been awakened [6-7]. The groups and laboratory-opening arrangements are shown in Table 2.

Table 2. Experimental Grouping and Laboratory Opening Status

Group Size	Task 1	Task 2	Task 3
1Y	Preparation, operation & data analysis		
3N	Operation	Loading	Recording
3Y	Recording	Disassembly measurement	Disassembly measurement
3Y	Operation	Recording	Bolt loading
2Y	Design	Assembly	

3.3 Reform of the Evaluation System

Given the defects in the previous single-criterion assessment system, a new system of many indicators has been introduced. Students are now graded on their completion of video-based task points, laboratory operations, experimental reports and virtual simulation performance. The particular assessment plan has been posted on the Xuexitong platform for the students to learn about. A task-oriented teaching method is used to guide students to complete all the steps of the experiment gradually. Based on the current teaching situation, the weights of the different assessment components will be adjusted dynamically according to the results of student learning, feedback from questionnaires and participation in class discussions. Thus, the iterative process will help the assessment system be reasonable and effective for students' learning [8].

3.4 Implementation of Innovative Project-Based Experimental Content

A new module of project-based experiments will be introduced to foster students' engineering design and all-around problem-solving abilities. Students are to watch the micro-lecture videos in advance and then, by themselves, build the mechanical structures mentioned in the project. Construct the physical model and then use MATLAB to build a virtual simulation for study and optimisation. Students independently complete the whole process of theoretical preparation, physical realisation and virtual verification in the workflow. The resulting project outcomes will be used as teaching materials for subsequent experimental classes to create a continuous cycle of content expansion and teaching innovation [9-10].

3.5 Compilation of the Experimental Guidebook for Mechanical Design Fundamentals

A set of experimental notebooks for mechanical design fundamentals has been prepared to help students learn by doing. This guidebook will present the goals, ideas and steps, etc., of all the experiments and data-analysis plans. It will help the students prepare for the experiment in advance, learn some basic information about it before class, and better absorb what they have learned in the experiment.

4. Conclusion

This paper addresses the following problems in experimental teaching of Mechanical Design Fundamentals: rigid teaching modes, low student engagement, a disconnect between virtual and physical experiments, and limited assessment methods. A four-in-one model of "micro-lecture preview, virtual simulation preview, open practice and diversified assessment" has been developed and rolled out.

A total of 36 micro-lecture videos (32'52" in length) have been created and uploaded to the Xuexitong platform to cover experiment preparation, principles, procedures, data analysis and virtual simulation. Laboratories were opened and flipped classrooms were used for experiments without safety risks to address equipment shortages and scheduling conflicts, and teacher-student interaction was strengthened. All four types of evaluation included achieving the goal of the video task and good laboratory behaviour. A corresponding experimental guide was also prepared for the unified teaching.

The revised model meets the requirements of "high-level, innovative and challenging" for a first-class course. It can inspire students to be more active learners, show their interest in mechanical innovation, and develop self-study, hands-on and creative thinking skills independently. The above methods have been successfully used in more than 5,000 undergraduate classes across various mechanical engineering courses and have shown good results. This study provides an excellent, feasible and repeatable reference for experimental teaching reform in mechanical engineering..

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