Research on Experimental Teaching of Mechanical Design Foundation Based on "Internet of Things + Cloud Platform" Technology

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Abstract. To address the issues of verification-oriented experiments, teacher-centered instruction, and assessment relying solely on experimental reports in Mechanical Design Foundation (MDF) course, this paper proposes a reformed teaching system based on IoT and cloud platform technology. A three-level progressive experimental system (basic verification—comprehensive design—open innovation) is constructed using reconfigurable equipment. Blended virtual-physical teaching mode is adopted, which integrates digital design, cloud platform and IoT technologies throughout the experimental process. A diversified whole-process evaluation mechanism emphasizing learning behavior data is established. Teaching practice shows that the experimental group significantly outperformed the control group in academic performance (54.5% achieving ≥80 points vs. 43.7% in traditional mode), with questionnaire results confirming high student recognition and good internal consistency (Cronbach's α=0.87). This study provides viable practical strategies for the digital transformation of mechanical engineering education.

Keywords: IoT in Education, Cloud Platform, Experimental Teaching, Mechanical Design Foundation

1 Introduction

Driven by technological revolution, modern equipment technology is rapidly advancing toward digitalization and intelligence. The transformation of the manufacturing industry has placed higher demand on the practical abilities and innovative competencies of mechanical Engineers. MDF is the core course for mechanical majors in Chinese universities, its experimental teaching serves as a critical bridge connecting theory and application, and facilitating the transformation of knowledge into ability. However, the current teaching of MDF generally has the following pain points: experiments remain predominantly verification-oriented, lacking in comprehensiveness and innovation; the teaching mode is teacher-centered, with students following predetermined procedures,

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which restricts their abilities in independent thinking and problem-solving ability; assessment relies on experimental reports, lacking effective monitoring and feedback on the learning process. These problems restrict the effective cultivation of students' engineering practice ability and innovative thinking.

The new generation of information technologies such as cloud computing, the Internet of Things, artificial intelligence, digital twins and virtual reality has provided new technical support and implementation path for experimental teaching. Soni and Taneja [1] explored Augmented Reality (AR) based learning environment, enabling students to visualize real-time data flows, interact with virtual components, and configure IoT systems in a risk-free setting. Alghazo et al. [2] revealed the diverse applications of AI in personalized learning, intelligent tutoring systems, digitization of engineering drawings, simulation and assessment, providing a systematic analysis for the deep integration of AI technology with mechanical engineering education. Crogman et al. [3] systematically reviewed the applications of virtual reality, augmented reality and mixed reality in experiential learning, pointing out that extended reality technologies can help learners transcend traditional barriers and enhance engagement, comprehension, and knowledge retention. Suhail et al. [4] reviewed the applications of augmented reality in engineering education and found that AR significantly improves visualization and interaction in mechanical engineering, enhancing student engagement and comprehension. Agal et al. [5] explored the application of IoT technology in remote engineering education and found that IoT significantly enhances the interactivity of laboratory teaching and student engagement, while also facing challenges such as disparities in technological access and the need for tailored pedagogical strategies. Shurui Z [6] discussed three innovative application methods of IoT technology in engineering practice teaching: virtual simulation experiments, real-time data acquisition and analysis, and intelligent device and system integration. Shiying L et al. [7] systematically elaborated the application value of IoT technology in information acquisition, interactive sharing, and intelligent analysis, thereby providing a theoretical basis for the deep integration of IoT technology with experimental teaching.

In this context, how to deeply integrate the new generation of information technology into the experimental teaching process and establish an experimental teaching system with practical engineering background is the research direction of the teaching reform in MDF course. Based on the “IoT + cloud platform” technology, this paper will systematically explore the technical path and improvement measures for experimental teaching of MDF from three aspects: experimental content, teaching methods and assessment management, aiming to provide reference experience for the digital transformation and teaching reform of similar courses.

2 Technical Support of Digital and Intelligent Experimental Teaching

Future experimental teaching supported by next-generation information technologies will transcend the constraints of time and space, resource limitations, and curriculum boundaries, thereby establishing a new educational form that integrates online and offline learning as well as virtual and physical interaction. Its core transformation is manifested in the following aspects: teaching subject shifts from teachers to students; teaching objective changes from skill training to cultivation of comprehensive quality; and teaching process transitions from uniform standard to personalized customization. In the context of the digital and intelligent transformation of education, the laboratory has introduced the practical teaching platform developed by Bell Data Technology Company. This platform consists of reconfigurable experimental equipment, teaching software, and an IoT measurement and control system. These three components work in synergy to collectively establish a virtual-physical integrated and data-driven practical teaching environment.

2.1 Reconfigurable Experimental Equipment

The experimental equipment adopts a standardized interface design, supporting rapid assembly, flexible reconfiguration and functional expansion, as shown in Figure 1. A single set of hardware can be reconfigured to produce a variety of typical engineering mechanisms, including more than ten engineering cases such as crank press, jaw crusher, and dump truck mechanism. Based on the experimental objective or innovative design requirement, students are allowed to disassemble, reassemble, and expand the functions of the machine. Through the process of self-determined construction, students can gain an understanding of the structure and assembly process of mechanical system, which is conducive to cultivate their systematic design thinking and engineering practice abilities.

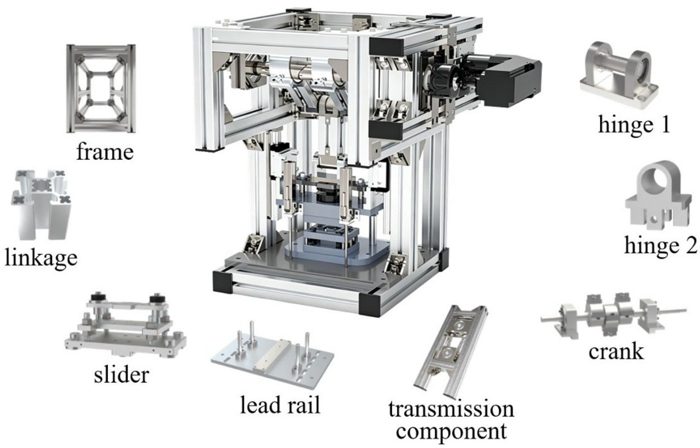

Fig. 1. Standard Reconfigurable Experimental Equipment (crank press).

2.2 Teaching Software Platform

The software platform is divided into a teacher side and a student side. On the teacher side, instructors can manage classes, configure experiments, monitor experiment progress and manage grades. On the student side, learners can carry out tasks such as mechanical scheme design, analysis of kinematic and mechanical principles, part design, simulating calculation, data analysis and experimental report. The platform integrates industrial software including cloud-based CAD/CAE, dynamics simulation and digital twins. It provides students with convenient digital design tools and a teaching resource library (2D, 3D and animation resources), thereby supporting a practice teaching mode of online and offline blending. Students complete their learning through online activities such as experiment preview, material selection, virtual assembly, data analysis and experiment report, while teachers can view experiment reports and grade online.

2.3 IoT Measurement and Control System

The IoT measurement and control system is the core part of data acquisition and control in digital-intelligent experimental teaching. It is mainly composed of six parts: sensors, data acquisition card, microcomputer, switching power supply, PLC and servo driver. The system uses Siemens 200SMART ST30 PLC and data acquisition card with a maximum sampling frequency of 250 kS/s, supporting three types of sensor interfaces: 6 channels for 5V sensors, 4 channels for 24V sensors, and 3 BNC interfaces for accelerometers, enabling compatibility with displacement, pressure and vibration sensors. Motor control is achieved through a XINJE servo motor interface (for speed control) and an electric push rod interface (for position control). Communication between the physical equipment and the cloud platform is realized via the MQTT protocol over WiFi, supporting cloud-based, remote, on-site, and offline control modes. These technical specifications ensure the reliability of real-time data acquisition and the accuracy of actuator control during the experiment. The working principle of the system is to convert the vibration, displacement, pressure and other signals on the equipment into electrical signals through sensors, send them to the USB data acquisition card for data collection, and then process the data by a microcomputer and send it to the software platform for data storage, analysis and visualization, as shown in Figure 2. The application of IoT technology enables online data acquisition and edge-side preprocessing, supports cloud-based device control and remote experiments, thereby breaking the limitation of time and space in traditional experiments.

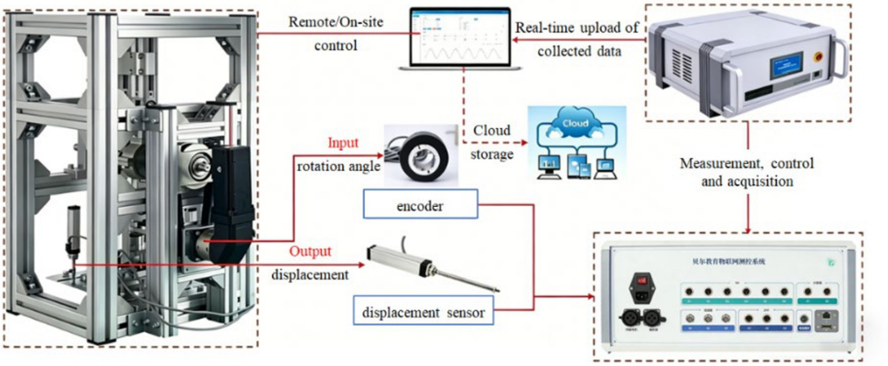

Fig. 2. Working Principle of the IoT Measurement and Control System.

3 Experimental Teaching Based on IoT-Cloud Platform

3.1 Experimental Content

Following the progressive pattern of competency development, the teaching content is divided into three levels: basic verified experiment, comprehensive design-based experiment, and innovative experiment. This allows the experimental content to gradually advance from verification to design, from single-task to comprehensive, and from passive to active learning. During the experimental process at different levels, students' engineering practical skills and comprehensive design abilities will be gradually enhanced.

Based on reconfigurable experimental equipment, students independently design mechanism (including configuration design, dimension design, performance verification), select modules to assemble the machine, design experiment (including testing principle, sensors, working condition and load, data input and output), install measurement and control devices (including mechanical structure modules, sensors, system integration and calibration), and conduct experimental test (including data acquisition and analysis). The whole process integrates the cognition, design and testing phases of the engineering case, solving the problems of scattered traditional experimental project and lack of innovation. The optimized experimental teaching content is shown in Table 1.

Table 1. Three Levels of Experimental Teaching Content.

Experimental type	Experimental item	Experimental mode
verified experiment	drawing of kinematic diagram of mechanism	online
	disassembly and assembly of complete machine	online and offline
	kinematic analysis and testing of machine/mechanism	online and offline
	static analysis and testing of machine/mechanism	online and offline
comprehensive experiment	structure design and performance testing of shafting system	online and offline
	assembly and performance testing of guide rail	online and offline
	assembly and performance testing of transmission system	online and offline

innovative experiment	innovative design of mechanism	online
	innovative design, assembly and testing of machine structure	online and offline

Verified experiments help students establish a perceptual understanding of mechanical structure, kinematics and mechanics principles, as well as to master the basic experimental testing method and operational skill. Students conduct observation, mapping, disassembly on virtual model or physical machine to understand the composition of mechanism, types of kinematic pair and motion transmission path. They analyze the kinematic and mechanics performance of mechanism under different configuration and dimension, laying the foundation for subsequent comprehensive design. Comprehensive experiments require students to apply knowledge from multiple courses to complete design tasks of a certain degree of complexity under the premise of the given experimental objective. Students are required to independently complete the entire process of design tasks, including scheme design, component selection, system construction, performance testing and data analysis. Innovative experiments are based on mechanical innovational competition or intelligent robot as the selection source. Students independently form teams, determine design scheme, make physical prototype, and verify its performance.

3.2 Experimental mode

The study adopts an experimental teaching mode of "online and offline, virtual-physical integration". Through the design, calculation, simulation, assembly and measurement-control of experimental machine, new technologies such as digital design, cloud platform and the IoT are integrated into the teaching process. This mode combines online virtual experiment with offline hands-on experiment organically, where the two complement each other and the virtual experiment serves the actual experiment. Students first carry out scheme design, simulation analysis and parameter optimization in a virtual environment, verifying the feasibility of the scheme, then they proceed to the laboratory for machine assembly and data acquisition. This mode not only reduces the experimental cost and safety risk, but also expands the depth and breadth of experiment. Students can explore complex scenarios that are difficult to access in traditional laboratories.

Taking the "kinematic analysis and testing experiment of machine/mechanism" as an example, this paper explains the experimental teaching process. The objective of this experiment is to enable students to master the kinematic analysis and testing method by analyzing the kinematic performance of mechanism with different configuration and dimension. The experimental process include: kinematics analysis, selection of working condition, selection of measurement-control materials, virtual assembly, physical assembly, data acquisition and data analysis.

Before class, students log in the teaching platform and conduct virtual experiment. They preview the experiment guide online and analyze the influence of different link lengths on the motion characteristic of mechanism with the kinematic analysis algorithm model. Then they select the measurement-control components required for the experiment, such as servo motor, sensors, encoders, and conduct the virtual assembly of the experimental machine and measurement-control device on cloud CAD platform.

By the cloud platform, students independently learn the experimental principle, algorithm model and design measurement-control scheme, completing pre-class preview and knowledge construction.

In class, students enter the laboratory and carry out practical operation. Based on the virtual assembly process, students assemble the experimental equipment in the lab, record the problems encountered during the assembly process, and troubleshoot them one by one. After debugging without errors, they conduct the experiment testing and data acquisition. During the class, teachers no longer simply impart knowledge in a one-way manner; instead, they guide students to engage in practical activities and solve problems, thereby achieving efficient use of class time and deep-level teaching interaction.

After class, students complete the data analysis and submit experimental report online. The experimental report includes experimental purpose, experimental principle, experimental process and step, experimental conclusion, and thinking questions. The teacher makes evaluation based on the experimental process data recorded by the platform and the experimental report.

The online and offline blended learning mode enables students to acquaint with the experimental procedure on the platform before class, focus on key operation and problem exploring during class, and perform repeated operations and comparative analyses via the platform after class. This experimental mode not only enhances students' self-learning ability and experimental operation efficiency, but also strengthens the integration of theory and practice, laying a solid foundation for subsequent engineering practice.

3.3 Teaching Evaluation

Online teaching platform can automatically record all learning behavior and outcome data of students throughout the entire experimental process, including experimental preview, scheme diagram, virtual assembly log, video and image of physical assembly process, data graph and experiment report. These data provide an objective basis for process-oriented evaluation. Based on the multi-dimensional data collected by the teaching platform, this study has established a diversified assessment system covering indicators such as experimental preview, scheme design, operation norm, teamwork, and outcome quality, as shown in Table 2. Furthermore, the weight of certain indicators can be appropriately adjusted in different experimental type.

Table 2. Experimental Teaching Evaluation Index System.

Phase	Indicator	Content	Method	Weight
Pre-class evaluation	preparation of experiment	view/read the online preview materials (courseware, video, experimental guide)	platform operation log	10
	virtual simulation operation	normativity of principle analysis, scheme design, parameter setting, and assembly process in virtual experiment	teacher grades online	20
In-class	material preparation	preparation of parts, tools and standard components	teacher observes and records on the site	5

evaluation	normativity of experimental operation	correctness of equipment operation normativity of experimental procedure	teacher observes and records on the site	10
	problem solving ability	analytical approach, solutions and adaptability in dealing with problems encountered during the experiment	teacher observes and records on the site	10
	teamwork	team contribution degree of member collaboration communication skill	teacher observes mutual evaluation	5
	quality of experimental data	completeness and accuracy of the data	teacher inspects on the site	10
Post-class evaluation	quality of experimental report	normativity of the report depth of data analysis discussion of experimental conclusions	teacher grades online	20
	thinking and expansion	quality of thinking questions further suggestions for improvement		10

4 Discussion and Evaluation of Teaching Effectiveness

To validate the effectiveness of the experimental teaching system, two parallel classes majoring in Weapon Launch Engineering are selected as practice subjects in our university. Class A (88 students) adopts the teaching mode of virtual-physical integration based on IoT-cloud platform, while Class B (87 students) adopts the traditional experimental teaching mode. There are no significant differences between two parallel classes in terms of prerequisite course grades and class composition. The distribution of experimental grades for Class A and Class B is shown in Figure 3. By comparison, Class A has 48 students in high-score segment (≥80 points), accounting for approximately 54.5%, which is significantly higher than 38 students of Class B (approximately 43.7%), there are 4 students (approximately 4.5%) in the low-score segment (≤69 points), significantly lower than 10 students of Class B (11.4%).

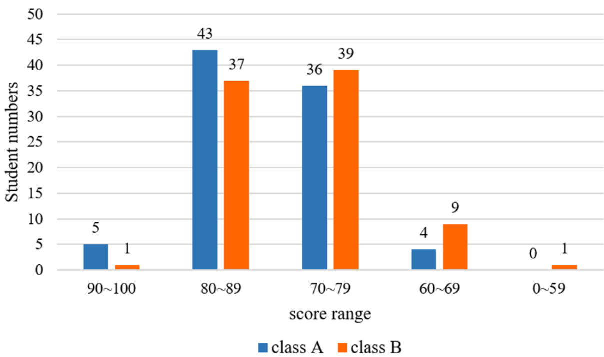

Fig. 3. Distribution of experimental grades.

The results of statistical significance testing are presented in Table 3. As shown, the mean score of Class A (M = 81.3, SD = 8.5) is significantly higher than that of Class B

(M = 76.9, SD = 9.2), with t(173) = 3.42, p < 0.001. The effect size (Cohen's d = 0.52) indicates a medium effect, suggesting that the teaching reform has actual significance. Additionally, as a supplement to non-parametric test, the Mann-Whitney U test also confirms a significant difference between two groups. Class A outperforms Class B in terms of excellence rate, average score and pass rate. These results demonstrate that the experimental teaching mode based on IoT-cloud platform significantly improved students' academic performance.

Table 3. Statistical Comparison of Grade Distributions between Class A and Class B.

Index	Class A (n=88)	Class B (n=87)	Test statistic	p-value	Effect size
Mean (SD)	81.3 (8.5)	76.9 (9.2)	t(173)=3.42	<0.001	Cohen's d=0.52
Median	82	78	U=2890.5	<0.001	—
High-score rate (≥80)	54.5%	43.7%	$\chi^2(1)=4.21$	0.040	$\varphi=0.16$
Pass rate (≥60)	100%	98.9%	Fisher's exact	0.497	—

To comprehensively evaluate the effectiveness of the teaching reform, an anonymous questionnaire survey is conducted among 88 students in class A at the end of the term. The questionnaire consists of 10 items designed from three aspects: learning interest and initiative, perception of ability enhancement, and identification with teaching mode. Likert scale method is adopted (5 = Strongly Agree, 4 = Agree, 3 = Neutral, 2 = Disagree, 1 = Strongly Disagree). Totally 88 questionnaires are distributed and collects 88 valid questionnaires with a 100% effective response rate. This study employs Cronbach's α coefficient to test the reliability of the questionnaire, as shown in Table 4. The results show the Cronbach's α coefficients of all scales are above 0.70, demonstrating the reliability of questionnaire. The questionnaire results are shown in Table 5.

Table 4. Questionnaire Reliability Analysis.

Dimension	Number of items	Cronbach's α
learning interest and initiative	3	0.83
perception of ability enhancement	4	0.85
identification with teaching mode	3	0.79
overall	10	0.87

Table 5. Questionnaire Result of Learners' Experience.

Item	No	Content	Mean
learning interest and initiative	Q1	Experimental teaching can stimulate your interest in learning.	4.17
	Q2	You will voluntarily spend time previewing and reviewing the experimental content.	4.16
	Q3	You are willing to explore extended experiments related to this course after class.	3.93
perception of ability enhancement	Q4	Experimental teaching is helpful for your ability to apply knowledge.	4.33
	Q5	Experimental teaching is helpful for your hands-on operation ability.	4.24
	Q6	Experimental teaching is helpful for your problem-solving ability.	4.13
	Q7	Experimental teaching is helpful for your innovative thinking ability.	3.97
identification with	Q8	You think that virtual simulation has guiding significance for physical experiment.	4.38

teaching mode	Q9	You think that blended teaching mode has improved the efficiency of experiment.	4.28
	Q10	You think that process evaluation is more reasonable than the simple evaluation based on experimental report.	4.22

In terms of learning interest and initiative, the mean score of Q1 and Q2 is 4.17 and 4.16 respectively, indicating that the online preview resources and virtual simulation provided by the platform effectively stimulates students' learning initiative. Mean score of Q3 is only 3.93, which is the lowest in the entire questionnaire, suggesting that there remains considerable room for improvement in guiding students to carry out extracurricular extended practice. In terms of ability enhancement, Q4 achieves the highest score of 4.33, while Q7 with 3.97 score is the lowest among the ability dimensions. It indicates that the teaching mode of virtual-actual integration enables students to conduct scheme design and simulated analysis in a virtual environment, followed by assembly, debugging and performance testing on physical prototypes offline, this closed loop of "design-simulation-implementation-validation" strengthens knowledge application ability. However, due to limited class hours, students have limited opportunities to participate in complete innovation training, resulting in deficiency of the experimental system in stimulating students' innovative consciousness. In terms of identification with the teaching mode, Q8 achieves a mean score of 4.38, the highest among all items. It demonstrates that students generally recognize the promoting effect of virtual simulation on physical experiments, validating the feasibility of the teaching mode. Mean score of Q9 is 4.28, indicating that online and offline blended teaching optimizes experimental time and improves learning efficiency. Q10 (4.22 score) reflects students' recognition of the diversified and whole-process evaluation mechanism.

It should be noted that this teaching practice is subject to limitations such as the pilot period (one semester), sample size (88 students), and course hours, and long-term comparative studies have not yet been conducted. The improvement of certain indicators may be affected by the novelty effect of students, and sustained effectiveness needs to be further verified through subsequent rounds of teaching practice. Moreover, the open innovative experiments (mechanism design and machine structure innovation) have already facilitated students′ participation in competitions, with some students converting their experimental projects into competition entries and win four awards (2 first prize, 1 second prize, 1 third prize) in Shaanxi Province of 12th National Undergranduate Mechanical Innovational Competition in China.

The implementation of this teaching system requires hardware and software support including experimental prototype, IoT measurement and control system and cloud platform. Experimental costs depend on the experimental item and content, as different experiments require different sensors, fixtures and mechanical transmission components. For institutions with limited resources, the proportion of virtual simulation experiments can be appropriately increased to reduce physical equipment units, and meanwhile the remote access function of the platform can be utilized to enable remote monitoring and operation of shared laboratory equipment. The system hardware adopts reconfigurable component design, supporting functional expansion and case updates. Besides standard prototype (such as press machine), universities can also develop experimental cases and projects with school characteristics to match their school-running orientation. The cloud platform is provided with free maintenance and technical support by the company within three years, including system upgrades, fault repair, data backup and other services, allowing students to access the platform via the Internet anytime and anywhere for previewing, simulation experiments and data analysis, without being constrained by time or space.

5 Conclusion

Based on the IoT and cloud platform technology, this paper systematically explores the reconstruction and optimization of the experimental teaching system for the MDF Course from three aspects: teaching content, teaching mode and evaluation reform. The effectiveness of the reform is verified through teaching practice, leading to the following conclusions:

(1) The paper proposes a three-level experimental teaching framework of verified, comprehensive and innovative experiment. The framework connects the process of mechanism cognition, scheme design, kinematic/static analysis and performance testing of reconfigurable experimental equipment, forming a complete chain from basic training to comprehensive application and then to innovative exploration. This framework provides a possible organizational approach for the systematic integration of traditional experimental projects.

(2) Blended teaching mode of integrating virtual and physical experiment has been established. Students complete preview, scheme design, simulating verification and virtual assembly online, perform physical equipment operation and data collection in laboratory, and finish data analysis and report submission online after class. Teaching practice has shown that the mode expands the temporal and spatial boundaries of experimental teaching and enhance students' learning autonomy and participation.

(3) Based on the learning behavior and outcome data automatically collected by the platform, the teaching evaluation system covering the entire process of pre-class, in-class and post-class has been preliminarily established. The evaluation mechanism can provide certain data support for the process-oriented management and continuous improvement of experimental teaching.

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