

Reform of Structural Comprehensive Experimental Graduate Courses Aimed at Cultivating Innovative and Applied Talents

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Abstract: In response to the issues in the "Structural Comprehensive Experiment" graduate course for civil engineering students, including the disconnect between course content and engineering practice, monotonous instructional methods, and outdated assessment mechanisms, industrial cases and intelligent detection technology are introduced to reconstruct the experimental teaching content. Task-driven learning and multi-role group collaboration were implemented to innovate the teaching approach. School-enterprise collaborative practices were incorporated to strengthen students' training in authentic engineering contexts. In addition, a diversified assessment system integrating process-oriented and outcome-oriented evaluation was established. Teaching practice demonstrated that the reform effectively enhanced students' abilities to operate intelligent inspection equipment, diagnose faults, and make sound engineering judgments, thereby facilitating their transformation from passive task executors into prospective engineers equipped with design thinking and problem-solving capabilities.

Keywords: Structural comprehensive experiment, Project exploration, Whole-process evaluation

1. Introduction

With the rapid development of intelligent construction technologies, the civil engineering industry is undergoing a profound transformation from a traditionally labor-intensive sector into a technology- and knowledge-intensive industry. China's 14th Five-Year Plan explicitly calls for the vigorous development of new construction modes, including intelligent construction and green construction. Traditional civil engineering graduate education tends to emphasize theoretical calculation and manual operation, particularly in the area of structural experimentation. It continues to rely on manual data reading, manual recording, and post-experimental data processing, and largely remains at the stage of confirmatory experiments and basic instrument operation. This training model is significantly disconnected from practical engineering applications on construction sites, making it difficult to meet the urgent demand for high-quality, innovative, application-oriented talent at the front line of the industry [1].

The "Structural Synthesis Experiment" course serves as a core practical component of civil engineering graduate education, fulfilling the essential role of integrating the principles of mechanics, structural behavior, and testing techniques. After graduation, students entering front-line positions in construction, inspection, supervision, and operation and maintenance are often required to independently perform tasks such as structural performance assessment, on-site load testing, and defect investigation. This, in turn, requires them to have developed solid practical competencies and a problem-solving mindset during their education.

However, from the perspective of current teaching practice, the "Structural Synthesis Experiment" course exhibits three prominent shortcomings. First, the experimental content remains focused on traditional verification, with students following the experimental guidebook step by step, which limits their understanding of experimental principles and boundary conditions and provides insufficient training in proactive design and troubleshooting. Second, the integration of experimental methods with intelligent technologies remains insufficient; for example, static resistance strain measurement has not yet incorporated wireless data acquisition systems and still relies primarily on manual balancing and recording. Third, the assessment method is overly narrow, often relying on the reasonableness of the conclusions presented in the experimental report as the primary scoring criterion, while lacking effective evaluation of procedural standardization, the ability to analyze anomalous data, and team collaboration.

These issues directly result in students being unable to cope with non-ideal conditions, sensor failures, and data noise in real engineering contexts even after completing the course, thereby creating a significant gap between the intended goal of cultivating innovative, application-oriented talent and actual training outcomes.

Therefore, the “Structural Synthesis Experiment” course requires systematic reform aligned with the current objective of cultivating innovative, application-oriented talent. The core direction of this reform is to reconstruct the practical teaching system under the guidance of intelligent technologies, enabling students not only to operate traditional instruments during the experimental process, but also to understand and apply modern technologies such as sensing, automated data acquisition, and data analysis to solve practical engineering problems^[2]. This study explores the reform pathway of a practical teaching model for cultivating innovative, application-oriented talent based on the teaching practice of the comprehensive experiment course, with the aim of providing a reference for the reform of similar graduate courses.

2. Analysis of the current teaching status of the "Structural Synthesis Experiment" course

2.1. Course teaching content and preliminary problem identification

Although the existing experimental design meets the basic competency requirements of civil engineering graduate students in structural engineering, the experimental content remains highly proceduralized, leaving limited room for independent student thinking. Taking the static loading experiment of a steel truss as an example, because this experiment is classified as non-destructive testing, instructors usually require students to perform loading strictly in accordance with the experimental guidebook and the prescribed loading levels in the textbook, while manually recording the stress and displacement changes at each measuring point, thereby verifying the consistency between the theoretical internal forces of the truss and the measured results. Although this approach ensures that the steel truss is not damaged, students have little opportunity to participate in the design of the experimental protocol, make independent adjustments to the loading sequence or measuring-point arrangement, or engage in active inquiry and innovation-oriented thinking.

2.2. Preliminary judgment on teaching methods and evaluation mechanisms

The “Structural Synthesis Experiment” course typically begins with theoretical instruction, through which students acquire foundational knowledge, followed by teacher-led experimental demonstrations designed to familiarize them with the experimental process. Students then replicate the instructors’ procedures to conduct the experiments. Although this demonstration-and-replication teaching mode can ensure the smooth completion of experiments, students remain in a largely passive role throughout the process and lack opportunities to independently address uncertainties such as equipment malfunctions, operational errors, and the feasibility of experimental protocols. At the same time, because theoretical teaching precedes experimental practice, students’ understanding of the relevant concepts may remain superficial and insufficiently connected to practical application.

In terms of the evaluation mechanism, course grades are composed of three components: regular attendance, experimental performance, and the experimental report. Among these components, the experimental report, as the most readily quantifiable indicator, accounts for the largest proportion, typically reaching 50%. The scoring criteria for experimental reports mainly focus on whether the data are complete and the calculations are correct, while lacking effective means of evaluating the rationality of the experimental design and the approaches adopted in response to data anomalies. This evaluation approach objectively overlooks the rigor of the experimental process and fails to cultivate students’ capacity for independent problem-solving.

2.3. Student feedback and summary of teaching pain points

First, students generally perceive the experimental content as disconnected from practical engineering applications. Many students report that the static resistance strain gauges and mechanical dial indicators used in the curriculum are rarely encountered on construction sites, where they have largely been replaced by wireless acquisition systems and automated monitoring equipment. As a result, the skills they acquire cannot be directly transferred to their internships or future professional practice, often requiring them to undergo additional learning. Second, students lack opportunities for trial-and-error exploration and

independent experimental design. Because all experimental procedures are predefined, even when students develop alternative ideas regarding a particular step, they have no opportunity to test or validate them. Some students have indicated that they would prefer to encounter “imperfect” experimental conditions, such as test specimens with initial defects, partially malfunctioning sensors, or sensor interfaces affected by corrosion or poor connections, in order to develop their genuine capacity for problem identification and resolution. Third, the experimental report has become the sole tangible output of student performance, yet it cannot fully reflect an individual’s experimental competence. Some students perform experiments in a standardized manner and provide authentic data, yet receive low scores because their final results are unsatisfactory; conversely, some students whose data appear to have been manipulated may receive high scores because the reported results seem reasonable. This evaluation bias undermines the motivation of students who are conscientious and practically engaged. These issues collectively indicate that the existing teaching model places excessive emphasis on verification and final results, while neglecting the integration of experimental design, fault diagnosis and handling, and intelligent detection methods, thereby creating a substantial gap between the current teaching approach and the objective of cultivating application-oriented talent.

3. Reform measures for classroom and experimental teaching mode of "Structural Synthesis Experiment"

3.1. Reconstruct teaching content driven by industry cases and intelligent means

The teaching content should be aligned with the current demands of the civil engineering industry, integrating theoretical instruction with practical training and incorporating advanced intelligent technologies. For example, theoretical instruction and practical training in static loading experiments should be delivered in a coordinated manner. While teaching the use of experimental devices and intelligent detection equipment, real engineering cases should be incorporated, such as comparative analyses of sensor or measurement-point selection in static loading experiments for prefabricated and conventional building structures, as well as the rapid seismic assessment of existing buildings. In this way, students will no longer engage only with standard test specimens, but will also be able to link standardized experiments to real engineering cases, understand the application of static loading tests across different structural types, and appreciate the core value of structural assessment [3].

Furthermore, the teaching content should substantially increase the use of intelligent technologies in structural nondestructive testing and assessment. In traditional teaching, owing to the constraints of the classroom environment, this component is usually dominated by theoretical instruction, and students lack opportunities for hands-on application. After the reform, campus buildings constructed in different periods can be used as field objects for investigation, and advanced testing techniques, such as the rebound method and ultrasonic testing, can be incorporated into the experimental component to guide students in conducting on-site inspection and testing activities. This learning approach can help students develop an intuitive understanding of how traditional testing methods and intelligent testing technologies influence final assessment results, thereby enabling them to adapt in advance to the latest intelligent operational practices in the industry.

3.2. Taking project exploration as the main thread, innovate teaching methods

The teaching method needs to shift from teacher-led one-way demonstration to student-centered active exploration [4]. Project-based learning provides an effective pathway for achieving this transformation. Instead of directly providing a complete experimental guidebook, teachers assign authentic engineering tasks, such as evaluating the residual load-bearing capacity of an existing steel truss platform or determining whether a prefabricated concrete column that developed cracks during lifting meets acceptance requirements [5]. Working in project groups, students complete the entire process of literature review, experimental scheme design, loading system development, measurement-point arrangement, and result analysis. Teachers provide only the necessary safety guidance and equipment support, while evaluation focuses on the soundness of the proposed scheme and the rigor of the analytical and argumentative process. This task-driven approach can effectively stimulate students’ initiative, as each decision directly influences the reliability of the final conclusions.

Group collaboration and multi-role task allocation are also key components of pedagogical innovation. Each experimental group is assigned roles such as project leader, testing engineer, data analyst, and safety supervisor, and these roles are rotated across successive experimental projects. The project leader is

responsible for coordinating progress and external communication; the testing engineer leads instrument installation and data acquisition; the data analyst is responsible for real-time data recording and processing; and the safety supervisor is tasked with checking the stability of the loading system.

3.3. Relying on real-life scenarios, strengthen practical teaching

The core of practical teaching enhancement lies in moving beyond the singular model of confirmatory experiments and shifting toward design-based, comprehensive, and innovative experimental formats [6]. Comprehensive experiments integrate multiple knowledge domains, for example by simultaneously conducting strain measurement, displacement monitoring, and crack-width recording under static loading, while also incorporating nondestructive testing methods to evaluate the initial quality of the specimen. Innovative experiments encourage students to refine existing experimental methods, such as designing a more convenient support fixture or comparing the effects of different bonding adhesives on strain transfer efficiency.

During instruction, the introduction of industry mentors and off-campus practice-base resources can extend the classroom into real engineering settings. Partnerships can be established with local testing institutions, design institutes, or construction companies to arrange for students to visit or participate in projects such as on-site load testing, pile foundation testing, and structural safety assessment, while industry engineers explain the key operational procedures and common troubleshooting methods associated with intelligent testing equipment in the field. When conditions permit, an authentic and relatively simple testing task can be used as a comprehensive course assignment under the joint guidance of industry mentors and faculty members.

4. Specific measures for the reform of the teaching evaluation system of "Structural Synthesis Experiment"

4.1. Strengthen process evaluation and focus on the performance throughout the entire experimental process

The primary shift in the reform of the evaluation system is from an exclusive focus on final results to greater attention to the entire experimental process. Process evaluation emphasizes the assessment of students' performance during the experimental preparation stage, including the thoroughness of background review, the soundness of experimental scheme design, their contributions to group discussions, and their adherence to operational standards and safety practices during experimental procedures [7]. Instructors can establish several observation points at each experimental stage and develop concise evaluation rubrics, such as whether the component surface is properly cleaned before strain gauge installation, whether faulty soldering occurs during the wiring process, and whether abnormal noises are carefully monitored and promptly recorded during loading. These observation points reflect students' work ethic and engineering professionalism. Through process evaluation, students become aware that each operational step is subject to assessment, thereby paying greater attention to detail and standardization, gradually developing sound engineering habits, and effectively reducing the passive compliance and peer dependence that characterized previous experimental classes.

4.2. Implement results-oriented evaluation, and emphasize data logic and problem analysis

Outcome-oriented evaluation no longer relies solely on whether the conclusions presented in the experimental report appear "perfect" as the primary basis for scoring. Instead, it comprehensively examines the logical consistency among the experimental design report, original data records, data processing methods, and final analytical conclusions [8]. Students are required to submit complete copies of their original data without deleting or modifying questionable values, and instructors will randomly select certain measurement points for review. When abnormal data fluctuations occur, students are encouraged to include a separate analytical paragraph in the report to proactively discuss possible sources of error, such as poor sensor contact, changes in environmental temperature, and uneven support friction, and to propose corresponding improvement measures. This design ensures that "imperfect data" are no longer treated as grounds for score deduction, but rather as an opportunity to demonstrate students' problem-solving ability and engineering judgment. More importantly, this evaluation method helps students recognize that perfect, noise-free data are rarely encountered in real engineering practice. The ability to identify patterns in complex or noisy data and provide reasonable explanations is the true manifestation of engineering competence. Overall, process-oriented and outcome-oriented evaluation

complement each other, jointly forming a fairer and more robust assessment system capable of reflecting students' actual competencies. This approach encourages students to focus on the substantive improvement of their competencies rather than pursuing a superficially polished experimental report.

5. Comparative Analysis of the Effectiveness of Teaching Reform Practices in "Structural Synthesis Experiment"

The above reform measures, as illustrated in Figure 1, have been systematically implemented in the "Structural Comprehensive Experiment" course for the 2023 cohort of Civil Engineering graduate students at Wuhan Polytechnic University.

Compared with the 2022 cohort, the reformed graduate course has integrated classroom-based theoretical instruction with experimental teaching, using different types of buildings constructed between 1995 and 2025, including large-span and frame structures, as investigation objects. New equipment has been introduced for nondestructive testing, significantly improving students' proficiency in operating intelligent testing equipment. During indoor experiments, non-ideal conditions such as sensor malfunctions and eccentric loading are intentionally introduced, encouraging students to engage in active problem-solving and greatly enhancing their ability to troubleshoot and make engineering judgments. Process evaluation and multi-role rotation have effectively curbed the phenomenon of "one student operating while the others merely observe," achieving a 100% raw-data completeness rate and significantly reducing repeated experiments caused by nonstandard operations.

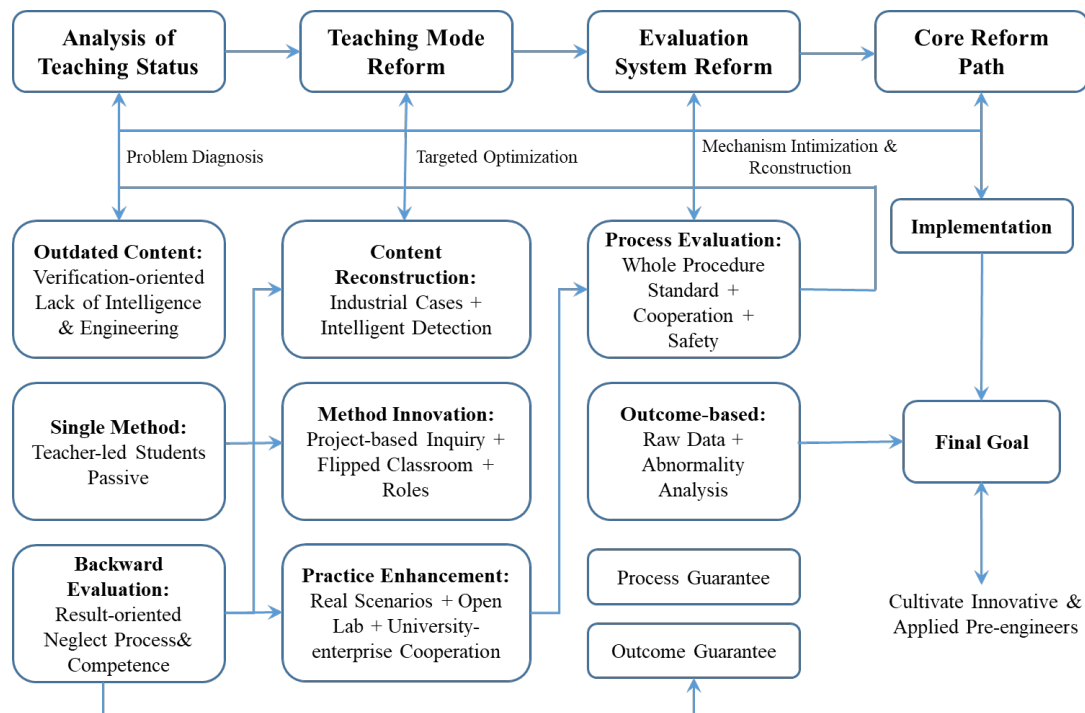


Figure 1: Problems and improvement measures

6. Conclusion

Addressing the issues of rigid experimental content, monotonous teaching approaches, and outdated assessment mechanisms in the "Structural Synthesis Experiment" course, this paper proposes a systematic reform pathway centered on project-based exploration, grounded in authentic engineering contexts, and guided by whole-process evaluation. Teaching practice has shown that introducing design-oriented and comprehensive experimental formats, implementing task-driven instructional strategies, and strengthening diversified assessment approaches that emphasize both process and outcomes can effectively stimulate students' motivation for active learning and significantly enhance their competencies in experimental design, fault diagnosis, and engineering judgment. In the future, it will be necessary to continuously update teaching content and engineering cases, explore cross-course practical projects, establish a long-term tracking and feedback mechanism, and iteratively optimize the reform

framework, in order to truly cultivate high-quality, innovative, application-oriented talent capable of adapting to the demands of industrial transformation and upgrading.

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