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Exploration and Practice of Teaching Reform in Multi-story and High-rise Building Structure Design under the Concept of Integration of Science and Education

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Abstract

The rapid evolution of civil engineering and the increasing need for interdisciplinary expertise have highlighted significant shortcomings in traditional teaching methods for multi-story and high-rise structural design courses. These shortcomings span teaching content, pedagogical approaches, and practical training. In response, the integration of scientific research and education has emerged as a promising direction for curriculum reform. Grounded in an analysis of the current state of these courses, this study pinpoints core challenges and proposes a reform model centered on a "research-driven teaching" philosophy.The proposed reform is operationalized through several key initiatives: the reorganization of course modules, the introduction of illustrative research cases into the classroom, and the joint development of hands-on training platforms with industry partners. This multi-faceted approach aims to foster teaching innovation and enhance student learning. To assess the viability of this model, we conducted a comprehensive evaluation of the course outcomes. Our findings demonstrate that the research-driven approach not only strengthens students' structural design capabilities and research skills but also effectively cultivates innovative thinking and improves their competence in practical engineering contexts. Consequently, this reform framework offers a valuable reference for the ongoing enhancement of multi-story and high-rise structural design education.

Keywords

Integration of science and education; Design of multi-story and high-rise buildings; Curriculum reformteaching practices.

1. Introduction

The "Guiding Opinions on Accelerating the Construction of 'Double First-Class' Universities and Disciplines" issued by the Ministry of Education [1] explicitly states: "Establish and improve a collaborative education mechanism where science and education integrate and mutually support each other, promoting the organic unity of knowledge transfer, scientific research, and capacity building." This is not only an urgent requirement for building world-class universities with Chinese characteristics but also an inevitable necessity for cultivating high-level talents to serve national strategic development [2]. The "integration of science and education" is currently a vital component of higher education reform. It aims to bridge the gap between teaching and learning through the feedback and permeation of scientific research results, thereby systematically shaping students' scientific critical thinking and innovative capabilities [3].

"Multi-story and High-rise Structure Design" is a key core course for civil engineering majors. Covering contents such as structural system selection, mechanical response analysis, seismic performance evaluation, and component design optimization, it serves as a pivotal course for students transitioning from theoretical cognition to engineering practice. With the rapid

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development of the civil engineering discipline and the elevation of practical engineering needs in recent years, traditional course models have begun to reveal several deficiencies. For instance, course contents are mostly confined to the mechanical application of code provisions, lacking integration with fields such as performance-based design, seismic fragility evaluation, and intelligent structural optimization. Teaching leans towards unilateral lecturing with insufficient student-teacher interaction. Furthermore, experiments and course designs remain at the level of manual calculation verification, lacking the support of high-precision finite element platforms and research analysis tools. Consequently, it is difficult for students to form a systematic and complete framework of engineering cognition, and their research awareness and innovative potential remain uninspired.

The integration of science and education provides a perspective and breakthrough for solving the aforementioned problems. By "using research to feed back into teaching," cutting-edge research achievements are systematically incorporated into the teaching process [4]. This ensures that the course content remains consistent with frontier developments, thereby stimulating students' developmental interests and enhancing their scientific research literacy and engineering practice capabilities [5]. Therefore, targeting the current teaching status of the "Multi-story and High-rise Structure Design" course, this paper proposes taking "research achievements feeding back into the classroom" as the main thread. It focuses on resolving specific schemes such as the reorganization of course content modules, the introduction of typical research cases, the co-construction of virtual-real integrated practical training platforms, and the permeation of intelligent design methods, alongside conducting multi-dimensional verifications. Practice demonstrates that this model effectively enhances students' capabilities in systematic analysis of complex structures, seismic performance testing, and structural optimization, cultivating their innovative consciousness and research thinking in structural design. By introducing real research project data and advanced analysis tools, students are more willing to explore parameters when solving open-ended problems, thereby expanding their engineering application capabilities. This study provides a replicable and promotable practical paradigm for teaching innovation in this course, and offers reference experience for deep course reform under the background of Emerging Engineering Education (New Engineering).

2. Current Teaching Status and Problem Analysis

"Multi-story and High-rise Building Structure Design" is a core pillar course in the civil engineering major. Its knowledge spectrum encompasses basic theories such as structural system selection, internal force calculation, and component design optimization, and extends to comprehensive ability training links like seismic performance analysis, and structural safety and serviceability assessment. It holds an irreplaceable position in shaping students' professional literacy and engineering practice abilities. However, constrained by traditional teaching models, this course still exhibits obvious shortcomings across multiple dimensions, including content systems, teaching methods, research articulation, and practical training. It struggles to meet the demands for cultivating compound talents who equally emphasize cross-disciplinary integration capabilities and innovative thinking under the background of Emerging Engineering Education [6]. The current teaching status and problem analysis are shown in Fig 1.

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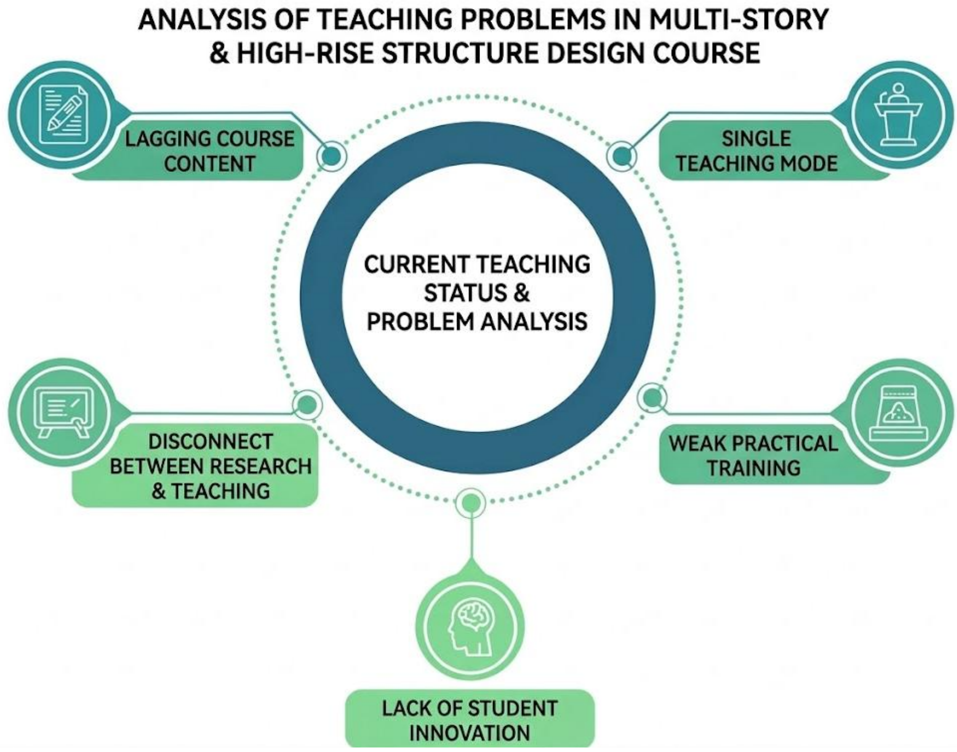

Figure 1. Teaching Status and Problem Analysis Diagram

2.1. Lagging Course Content and Lack of Frontier Updates

Current course content is updated slowly and fails to timely reflect frontier advancements in the discipline. The course system is primarily built upon national codes, with teaching content long focusing on frame-shear wall structures, requiring students to master numerous standard formulas and code provisions to train their basic calculation and design abilities. However, as engineering practice develops towards refinement and intelligence, new methods such as performance-based design, seismic fragility assessment, and structural optimization based on intelligent algorithms have been widely applied in the industry, enabling more accurate predictions of actual structural behaviors. In contrast, the updating of the knowledge system in university classrooms lags behind; these cutting-edge contents have not yet been systematically incorporated into the teaching syllabus. This results in students having a limited understanding of the discipline's development dynamics, and there is a distinct gap between what they learn and actual engineering demands, potentially affecting their future ability to solve complex engineering problems.

2.2. Single Teaching Method and Insufficient Interactivity

Regarding teaching methods, the traditional model is relatively monolithic and lacks effective interaction. The classroom relies heavily on teacher lectures and blackboard derivations, forming a fixed routine of "teacher speaks, students take notes." The utilization of multimedia-assisted teaching is inadequate, the introduction of real engineering cases is limited, and the classroom lacks heuristic questioning and deep interactive segments. This leads to low student participation and weak willingness to think actively. As course content becomes increasingly complex and the need for cross-disciplinary integration strengthens, this unidirectional, linear teaching approach is no longer suited for high-level learning requirements. It not only restricts the cultivation of students' independent learning abilities but is also detrimental to the formation of their cooperative inquiry literacy.

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2.3. Disconnect Between Research and Teaching, and Poor Resource Conversion

Cutting-edge research achievements obtained by teachers in fields such as structural optimization design, seismic performance analysis, and novel material components have not been systematically integrated into the course teaching system, resulting in an obvious "disconnect" between research and teaching. Constrained by the inherent tension between teaching and research tasks and the contradiction in resource allocation, the pathway for transforming scientific research outcomes into teaching content is obstructed and ineffective. Consequently, it is difficult for students to encounter the latest developments of the discipline during their coursework, and their research thinking and frontier awareness are not effectively nourished [7]

2.4. Weak Practice and Experimental Links, Lacking Guidance in Research Methods

Currently, the content arrangement for the experimental and design components in the course is relatively fixed. Students mainly conduct manual calculations based on code provisions for verification or analyze the mechanical performance of a single component. The course has not incorporated practical operational training on common software, such as analysis tools like ETABS, SAP2000, or OpenSEES. The course also lacks exploratory and open-ended practical projects that reflect modern scientific research methods. Therefore, when completing the course design, most students can only follow fixed steps for calculations. They rarely get opportunities to use advanced tools to tackle complex problems in actual engineering. Such a setup limits the cultivation of students' comprehensive abilities and is not conducive to developing the habit of solving problems innovatively.

2.5. Insufficient Student Innovation Ability, Comprehensive Literacy Needs Improvement

Guided by the current teaching model and grading criteria, many students understand the course objectives too simply, believing it is merely about "mastering code provisions and completing required calculation tasks." This perception limits the depth and breadth of students' learning. During the learning process, students rarely take the initiative to deeply explore problems, and their ability to independently handle complex problems in actual engineering is not fully exercised. Although most students can complete the course design according to the teacher's requirements, the submitted proposals are often very similar, lacking personal viewpoints and creativity.

3. Reform Concept and Overall Ideas

3.1. Reform Concept

Driven by the construction of "Double First-Class" initiatives and Emerging Engineering Education, the talent cultivation goal for the civil engineering major has systematically shifted from initial code-compliant design towards scientific research literacy and engineering innovation capability. The concept of integrating science and education advocates deeply implementing the coupling of teaching and research, giving full play to the infiltration and renewal of teaching practice by scientific research achievements, so that course content constantly focuses on the frontiers of discipline development. To achieve full-process synergy in the "Multi-story and High-rise Structure Design" course, it is necessary to fully integrate teachers' latest research achievements in structural optimization design, seismic fragility evaluation, and the application of intelligent algorithms into course teaching. This forms a dynamically evolving knowledge system that practicalizes abstract theories by introducing

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typical engineering cases, building an entire knowledge chain from codes to engineering. Simultaneously, it leverages research tools like finite element analysis platforms and intelligent optimization algorithms to enhance students' simulation and innovative design capabilities in complex engineering scenarios. In terms of teaching organization, various activities such as seminar-style teaching, flipped classrooms, and group collaboration are utilized to stimulate classroom vitality and cultivate students' autonomous inquiry and teamwork capabilities. Regarding the evaluation mechanism, closed-book exams are broken down to construct a full-process, multi-dimensional assessment method encompassing knowledge comprehension, case analysis, course design, and thematic research.

3.2. Overall Ideas

Based on the concept of integrating science and education, a closed-loop teaching system for the "Multi-story and High-rise Structure Design" course was systematically constructed, driving comprehensive innovation in teaching content, methods, and models from four dimensions. First, course content is no longer confined to traditional textbooks; instead, teachers are encouraged to systematically transform cutting-edge achievements—such as structural optimization, seismic fragility analysis, and intelligent algorithm applications—into modularized teaching cases and thematic content. This approach continuously enriches course resources and naturally guides students to establish research thinking and broaden their academic horizons during the teaching process. Second, the course selects representative real-world high-rise building projects as a main thread running through the entire process of theoretical explanation, classroom seminars, and course design. Through the progressive path of "cases guiding theory—theory analyzing cases—cases driving design," it helps students build a complete knowledge chain from code cognition to engineering judgment, effectively bridging the disconnect between theory and practice. Third, a dual-layer support system of "basic course experiments + scientific research exploration platform" was established. On the basis of consolidating traditional mechanics experiments, finite element software like ETABS and OpenSEES was introduced to enhance students' simulation analysis, parameter optimization, and innovative design capabilities in complex engineering scenarios. Finally, the course breaks away from the traditional "one exam determines the grade" evaluation method and establishes a comprehensive evaluation mechanism covering the entire process. The content covers aspects such as knowledge comprehension, case analysis, course design, research reports, and teamwork, specifically increasing the grading weight for segments like innovative design, scheme optimization, and scientific research reports. Consequently, the teaching segments form a virtuous cycle of "theory laying the foundation, research providing guidance, and practice reinforcing." This cycle effectively promotes a systemic transformation of the course teaching model, making it gradually exhibit new characteristics of being research-oriented, interactive, and intelligent. The overall path of the reform is shown in Fig 2.

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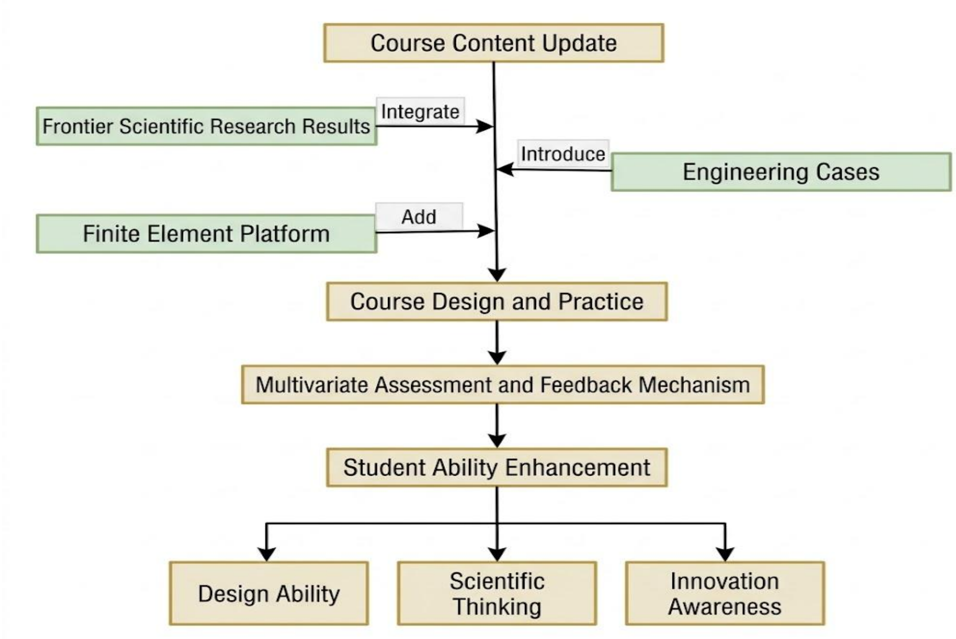

Figure 2. Overall Framework Diagram of Teaching Reform

4. Teaching Reform Practice

Based on the concept of integrating science and education and the idea of "research feeding back into teaching," the teaching reform of the "Multi-story and High-rise Structure Design" course was carried out in aspects such as content updating, case introduction, practical training platform construction, integration of intelligent methods, and improvement of assessment methods.

4.1. Course Module Reconstruction: From Code Impartation to Research Guidance

In the traditional course system, teaching content revolves around code derivations and component design, focusing on the explanation of theoretical formulas and code provisions. This results in students mastering calculation skills but struggling to form an overall cognition and innovative thinking regarding structural systems. To resolve this issue, the specific reform reconstructed the course structure into four major modules: theoretical foundation, engineering cases, scientific research methods, and innovative design. The "Theoretical Foundation" module systematically organizes core contents like structural system selection, internal force analysis, and component design, laying a solid professional foundation for students. The "Engineering Cases" module embeds typical high-rise building examples into each knowledge unit, such as the complete analysis and design process of a frame-shear wall structure, promoting the integration of abstract theory with engineering reality. The "Scientific Research Methods" module introduces cutting-edge directions like performance-based design, seismic fragility analysis, and structural optimization algorithms, expanding students' horizons, stimulating their exploratory interests, and cultivating their ability to discover and analyze problems. The "Innovative Design" module encourages students to break through code restrictions in their course design, propose personalized schemes, and utilize finite element platforms and intelligent algorithms to complete exploratory practices with scientific research content, strengthening their innovative consciousness and comprehensive design capabilities. Through the aforementioned modular reconstruction, the course objectives achieved a deep transition from "mastering codes" to "driving innovation," and the teaching model shifted from "knowledge infusion" to "research guidance." This formed a virtuous cycle of "theory laying the

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foundation, research providing guidance, and practice reinforcing," effectively driving the systematic transformation of the course towards a research-oriented, interactive, and intelligent direction.

4.2. Introduction of Scientific Research Cases: Cutting-edge Support for Classroom Teaching

Teachers convert their own scientific research achievements into teaching cases, forming a two-way interaction between research and teaching. In the structural optimization design section, an optimization case based on the reinforcement ratio of frame columns is set up; in the seismic performance analysis section, a high-rise building fragility evaluation case based on incremental dynamic analysis is established, connecting relevant knowledge with code calculations, performance evaluation, and scientific analysis. In the detailing measures design section, experimental research conducted by the research team on novel connection joints is used as a teaching discussion case. This guides students to understand the application value of scientific research achievements in engineering, enhancing their engineering value cognition capabilities.

4.3. Construction of Experimental and Research Platforms: Building Diversified Practical Support

The experimental component is the focal point of the course reform. Relying on existing laboratories and software platforms, a dual-support system of "course experiments - scientific research experiments" was constructed:

Course Experiments: Relying on mainstream design software such as ETABS and SAP2000, students are guided to complete parameterized modeling, load analysis, and code compliance verification for high-rise building structures. This systematically trains their digital design and analysis capabilities, solidifying their foundation for engineering practice.

Scientific Research Experiments: The OpenSEES platform is introduced to guide students in conducting structural seismic performance research based on nonlinear time-history analysis. By setting different intensity ground motion inputs, students observe the entire response process of the structure from elasticity to collapse, cultivating their cognition of complex mechanical behaviors and their capability for scientific inquiry.

Experimental Expansion: Students are encouraged to connect course design with scientific research training. Based on their completed course design schemes, they further carry out exploratory content such as incremental dynamic analysis, fragility assessment, or structural optimization based on intelligent algorithms. Through the construction of the above practice platforms, students can master the operational skills of modern engineering software proficiently, and initially form comprehensive abilities to solve complex engineering problems using scientific research methods.

4.4. Integration of Intelligent Methods: Enhancing Student Innovation Capabilities

In the course design and practical teaching segments, exploratory tasks are established to guide students in systematically applying intelligent optimization algorithms to the structural design process. Task example: Students are required to conduct multi-objective optimization of the column reinforcement ratio in high-rise frame structures based on the particle swarm optimization algorithm. The optimization objective is set to minimize the structural inter-story drift angle, constrained by the condition that the peak acceleration response does not fall below a specific threshold. Comparative analysis: By systematically comparing the differences between intelligent algorithm optimization results and traditional code-based design schemes, students are guided to conduct critical analysis from dimensions such as structural safety

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margins, material economy, and scheme innovativeness. This helps them deeply understand the essential differences between the two design paradigms in theoretical foundations and implementation paths. Outcome presentation: Students must submit a research report conforming to academic norms, completely presenting the full research process encompassing problem modeling, algorithm implementation, numerical simulation, result verification, and conclusion summarization. This strengthens students' scientific logical thinking, data visualization capabilities, and academic writing literacy. This teaching practice deepens students' understanding of the application value of intelligent algorithms in the engineering field, cultivating their innovative ability to solve complex engineering problems.

4.5. Teaching Interaction and Assessment Reform: Emphasizing Full-Process Evaluation

To deepen the teaching model reform and enhance students' classroom participation and comprehensive ability literacy, the teaching organization methods and assessment evaluation mechanisms were systematically reconstructed:

Classroom Model Reform: Implementing flipped classrooms and seminar-style teaching centered on students. Students are required to complete the reading and analysis of designated scientific literature before class, while class time is dedicated to typical case seminars and frontier problem inquiries.

Group Project Collaboration: Course design projects are carried out in groups to simulate team collaboration models in real engineering contexts. During project advancement, students must complete role allocation, scheme demonstration, task coordination, and outcome integration, enhancing their communication, collaboration, and collective problem-solving capabilities.

Multiple Assessment System: The assessment method shifted from a single exam to a multi-dimensional evaluation. This system focuses on process-oriented evaluation and ability orientation, comprehensively reflecting students' academic literacy and practical abilities. The assessment system is shown in Fig 3.

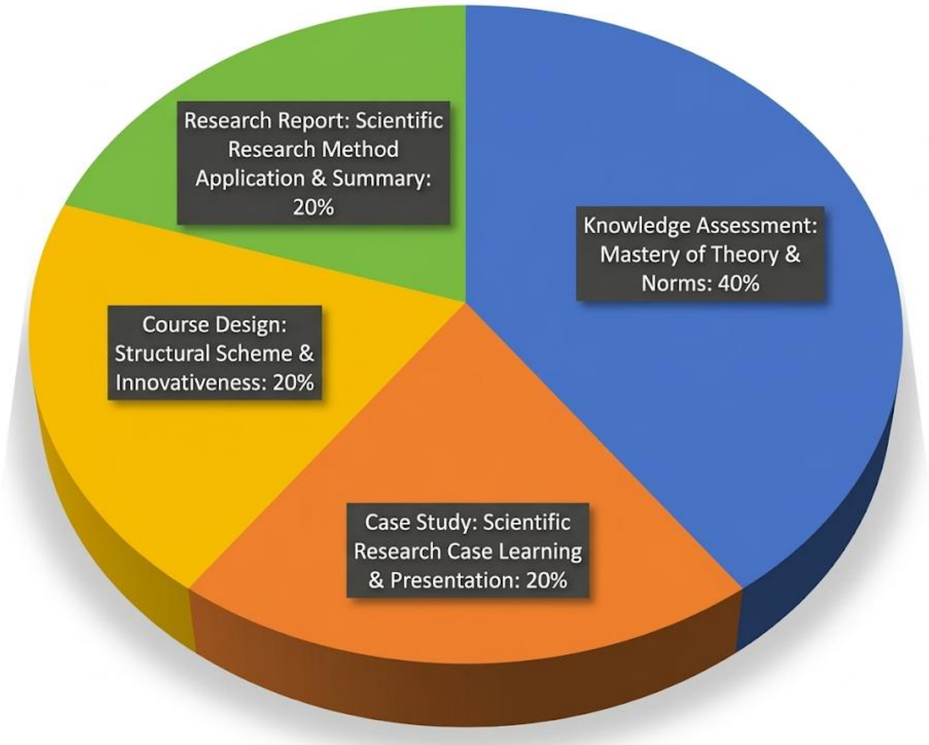

Figure 3. Multiple Assessment System Diagram

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This evaluation system is fundamentally guided by process-oriented assessment, systematically inspecting the depth of students' mastery of professional knowledge, their ability to apply scientific research methods, and the comprehensive literacy of their innovative thinking. Reform Effects and Discussion

5. Reform Effects and Discussion

To investigate the teaching effectiveness of the "Multi-story and High-rise Structure Design" course under the background of science-education integration, assessments were conducted on participating students via questionnaires and learning outcome statistics, and comparative research was carried out against student groups under the traditional teaching model. Data analysis indicates that the new teaching model has achieved marked results in enhancing students' design levels, research literacy, and innovative thinking

5.1. Student Classroom Feedback: Significant Increase in Participation and Learning Interest

Since the course implementation, students reported a more relaxed and highly interactive classroom environment. In the questionnaire, 82% of students believed that research cases made theoretical knowledge more concrete; 76% felt that flipped classrooms and group discussions significantly boosted their learning enthusiasm; and 69% thought that introducing research methods in the course expanded their disciplinary knowledge. These results all indicate that the introduction of scientific research cases and interactive teaching has significantly elevated students' learning interest and classroom participation levels.

5.2. Learning Outcomes: Synchronous Enhancement of Course Design and Research Capabilities

After the reform, the course design process no longer strictly adheres to manual calculations based on codes; instead, students are allowed to use research equipment/software for design. Comparing the course design outcomes of the past three years shows that before the reform, student designs primarily aimed to "meet code requirements." After the reform, over 60% of students proactively introduced performance-based design methods or optimization algorithms, resulting in an improvement in design outcome quality. Some excellent course designs, under teacher guidance, were expanded into graduate research topics or the basis for undergraduate graduation designs. This demonstrates that the teaching reform has achieved certain effects in improving students' innovative capabilities and scientific research practice levels.

5.3. Connection Between Research and Graduation Design: Two-way Promotion of Teaching and Research

Through the integration of coursework and research, some students are able to master scientific research methods early during their undergraduate studies, facilitating subsequent graduation designs and postgraduate research. For example, some students applied optimization algorithms learned at school to their graduation designs, researching the impact of different reinforcement ratios on structural seismic performance. Others, guided by teachers, authored research papers or participated in academic competitions or research projects. This makes "research feeding back into teaching" an effective transitional format for current students moving from learning to researching.

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5.4. Engineering Application Ability: Tighter Integration of Theory and Practice

In the experimental and practical components, students gained a preliminary understanding of structural modeling and linear/nonlinear analysis methods using software like ETABS, SAP2000, and OpenSEES. 78% of students indicated that after completing the full course, they could independently perform modeling and analysis of high-rise structures; 54% had preliminarily conducted performance design and fragility testing. Some students noted during corporate internships that the software and research methods learned in the course were valuable for engineering applications. The course reform has improved students' engineering adaptability and innovative application capabilities.

5.5. Results Statistics and Discussion

To further quantify the reform effects, the project team compiled statistics on the outcomes of the latest two cohorts of students, as shown in Table 1.

Table 1. Comparison of Student Outcomes Before and After Reform Implementation

Indicator	Before Reform (Traditional Model)	After Reform (Science-Education Integration Model)	Increase
Excellent rate of course design (≥85 points)	32%	58%	↑26%
Proportion of students actively applying scientific research methods	15%	62%	↑47%
Proportion of students able to independently complete nonlinear analysis	10%	48%	↑38%
Proportion of graduation designs combined with scientific research topics	12%	36%	↑24%
Student satisfaction with the course (questionnaire survey)	68%	89%	↑21%

The data in Table 1 demonstrates that the teaching reform has significantly elevated students' research capabilities and innovative consciousness, and course satisfaction has also noticeably improved.

5.6. Discussion

Comparative analysis reveals that this course reform effectively alleviated the chronic problem of the "disconnect between teaching and research," forming a virtuous cycle of "research driving the course, and the course promoting research." However, some challenges persist during practice:

Increased teaching burden for teachers: Organizing research cases and updating the course require more effort.

Evident differences in student abilities: Some students with weaker foundations experience difficulties in applying scientific research methods.

Insufficient resource support: The course requires support from more practical training platforms and software licenses.

6. Conclusion and Prospects

Taking the "Multi-story and High-rise Structure Design" course as the research object, this paper explores teaching reform paths based on the concept of science-education integration. By means of "research feeding back into teaching," the latest scientific research achievements,

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methods, and technologies are integrated into the course system. The research-driven framework for improving the course system is shown in the figure.

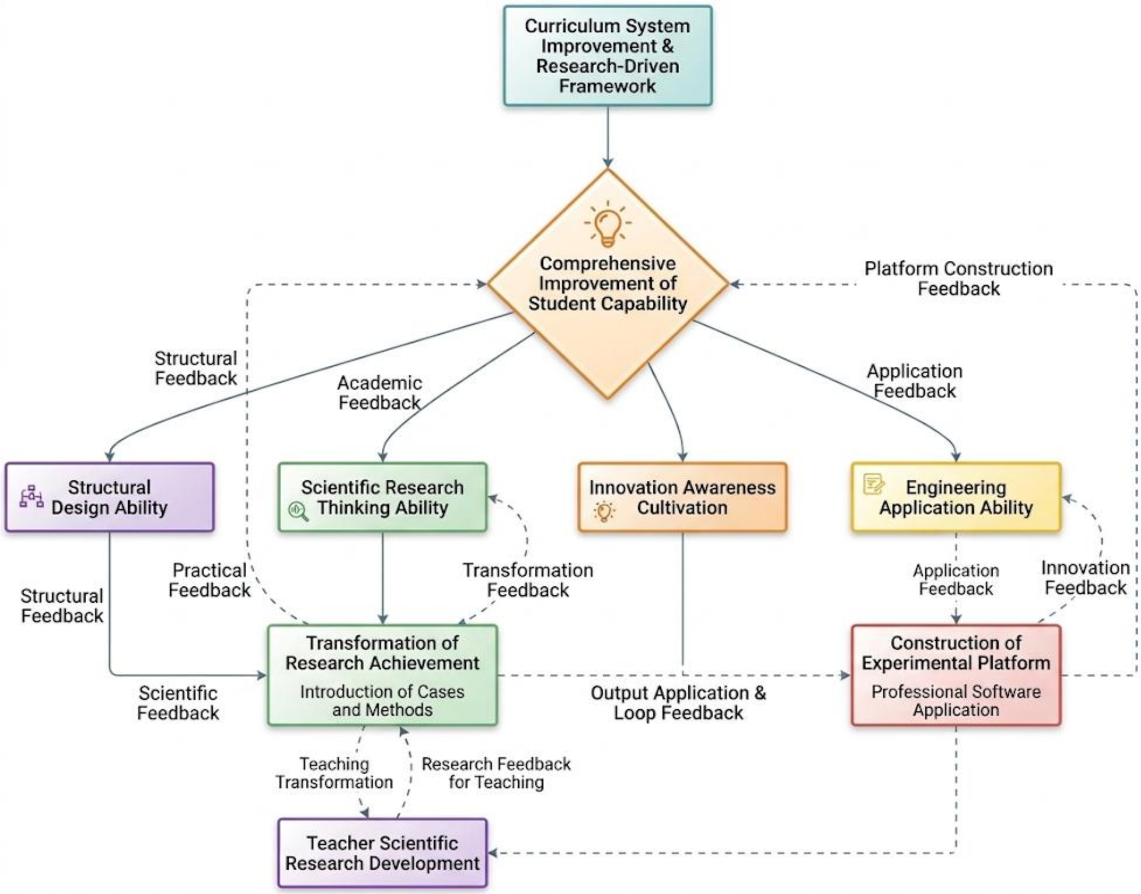

Figure 4. Course System Diagram

Research and practice indicate that this teaching reform has achieved significant results in the following aspects:

A more sound course system. By establishing a course framework of "theoretical foundation - engineering cases - scientific research methods - innovative design," it promoted a fundamental shift in teaching content from "code-oriented" to "research-driven."

Deep integration of research and teaching. The course introduced cutting-edge research cases and advanced research methods, effectively broadening students' disciplinary horizons and fostering an organic articulation between teaching and research.

Substantial progress in experimental and practice platform construction. By introducing professional software platforms like ETABS, SAP2000, and OpenSEES, students' engineering modeling and research analysis capabilities were improved.

Universal enhancement of students' comprehensive abilities. The course reform strengthened students' capabilities in structural design, research thinking, innovative consciousness, and engineering application.

Achievement of two-way promotion between teaching and research. The reform not only significantly boosted students' research abilities but also provided an effective pathway for teachers to convert research achievements into teaching resources.

However, areas needing improvement also emerged during the reform practice. First, teachers need to invest more in course design, and the organization of research cases and teaching resources must be further strengthened. Second, there is large variance among students; some encounter difficulties in learning scientific research methods. Third, the construction of experimental and research platforms is not yet perfect, and the course reform has significant

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demands for funding and resources. Future reform and development directions mainly include the following aspects:

Based on different student ability levels, pilot stratified courses by running foundation reinforcement classes and research expansion classes concurrently.

Establish a research case database and a teaching resource database to achieve resource sharing and dynamic updating for the "Multi-story and High-rise Structure Design" course.

Further strengthen cooperation with design institutes and construction enterprises to jointly introduce engineering practices and research achievements into the classroom, realizing a trinity of scientific research, teaching, and engineering application.

Establish a long-term course tracking and feedback mechanism to adjust course content according to student and industry needs. Research exploration and practice show that science-education integration can provide ideas and directions for the reform of the "Multi-story and High-rise Structure Design" course. In future course reforms, through continuous refinement of the course system and teaching resources, and the ongoing integration of research and teaching, the talent cultivation quality for the civil engineering major will be promoted and improved.

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