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Assessment and Restructuring of an AI-Enabled Course on Mechanical Equipment Structural Design

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Abstract: The course on mechanical equipment structural design faces structural challenges in transitioning from empirical imitation to intelligent judgment. The core contradictions of this course currently include: the tension between the highly context-dependent nature of structural design knowledge and traditional standardized teaching approaches, the misalignment between the rapid generation of design solutions by artificial intelligence(AI) and the gradual cultivation of engineering judgment capabilities, and the renewed manifestations in which structural design is difficult to teach and difficult to learn of the classic dilemma in the intelligent era. Grounded in the policy framework of the "AI + Education Action Plan" and incorporating cutting-edge AI application research in mechanical design education, this paper proposes a restructured pedagogical philosophy characterized by a process of judgment-first, process-driven, and human-machine collaboration. The study posits that the core value of structural design courses lies not in training students to draw correct diagrams, but rather in cultivating their engineering judgment when confronted with uncertain constraints. The value of AI empowerment lies in liberating students from low-level activities, such as referencing design catalogs and replicating existing drawings and allowing them to focus on comparing structural solutions, predicting failure paths, and developing decision-making logic under given constraints. Accordingly, this paper proposes a systematic restructuring plan across four dimensions: redefining course objectives, reorganizing the curriculum framework, innovating teaching modalities, and reforming evaluation mechanisms.

1. Introduction

Mechanical equipment structural design course serves as a pivotal link in the curriculum system for mechanical engineering disciplines, bridging foundational knowledge with practical application. It requires students to integrate principles of mechanics, material properties, manufacturing constraints, and functional requirements into concrete structural solutions, such as how to arrange shaft steps, how to position and secure bearings, how to design mold cavities for housings, and how

to implement sealing mechanisms. These seemingly minor considerations are precisely the most challenging aspects of mechanical design[1,2]. However, structural design instruction has long faced an awkward reality, as the course is difficult to teach, difficult to learn, and difficult to assess[3,4]. Teachers generally find it challenging to explain structural concepts, and students commonly find structural design tedious, and the instructional outcomes are often unsatisfactory. The integration of AI technology has provided an opportunity to re-examine this classic dilemma. As generative AI can rapidly generate diverse structural design alternatives, and as intelligent agents can assist in identifying design flaws, the core question of structural design education has been reposed: What should the curriculum teach? And if AI can handle tasks such as referencing design catalogs and simulating structures, where should the value anchor of such a curriculum be placed? This paper aims to address this question[5,6]. By analyzing the unique contradictions inherent in structural design courses and drawing on practical teaching experience in AI-enabled mechanical design, we propose a curriculum restructuring strategy tailored to the intelligent era.

2. The Unique Dilemmas and Transformative Opportunities of Mechanical Structural Design Course

2.1. The Underlying Reasons Why Structural Design Courses are Difficult to Learn

The teaching challenges in structural design stem not from technical issues in instructional methodology, but rather from the inherent nature of the body of knowledge. Design knowledge in structural engineering is highly context-dependent and characterized by its unstructured nature. Unlike strength calculations, which can be governed by well-defined formulas, structural design decisions often depend on multiple interacting factors: the nature and direction of loads, requirements for assembly and disassembly, feasibility of manufacturing processes, availability of materials, cost constraints, ease of maintenance, and even the designer's experiential intuition. These factors are difficult to reduce to a unified set of rules. As early researchers in education have noted, there remains no comprehensive and mature guiding theory for structural design in mechanical engineering to date. Moreover, structural design itself does not follow simple, predictable patterns. Instead, it relies primarily on the designer's practical industrial experience and design expertise.

Knowledge that can’t be fully and clearly articulated through language or text can only be gradually internalized through prolonged immersion in practical experience. To acquire solid structural design capabilities, students need to actively engage with a wide array of real-world engineering cases and personally undergo a progressive development journey—from imitating existing solutions to grasping their core logic and from deeply understanding design rationale to making independent design judgments. However, traditional university design courses are often constrained by fixed class hour allocations and limited teaching resources, making it difficult to provide students with sufficient high-quality case studies, nor to offer each student ample opportunities for training in independent design judgment. Under such conventional training models, students are limited to a finite number of exercises, which ultimately results in only a vague, catalog-like impression of various design outcomes, rather than the capacity to formulate independent design judgments capable of addressing real-world challenges.

The challenges inherent in structural design evaluation have further exacerbated pedagogical difficulties. In the fields of engineering design and product development, structural solutions often do not have a single correct answer. For a given, well-defined functional requirement, there can frequently be multiple distinct structural approaches to its realization. Each finalized solution has its own unique scope of applicability, along with associated trade-offs in terms of development effort, cost, performance, and other relevant factors. The traditional binary evaluation framework based on

a black-and-white distinction between correct and incorrect struggles to accurately gauge the true proficiency level of designers in structural design.

2.2. AI Induces Problems Reconfiguration Rather Than Problem Solving

The capabilities of generative AI in the conceptual design phase have already been preliminarily validated. Research indicates that image generation models are frequently employed to generate image design stimuli. Consequently, by integrating images from diverse products, creative generation can be further enhanced. In the field of mechanical equipment structural design, AI can generate preliminary structural design sketches based on functional descriptions. If this capability is appropriately integrated into educational settings, it could significantly lower the psychological barrier for students when undertaking structural design tasks. However, the limitations of AI are equally pronounced. Some studies have indicated that generative AI may exhibit issues in mechanical engineering education, such as subtle computational errors and inadequate handling of symmetry. Consequently, the output results of AI applications in this domain require careful verification. It means that AI-generated solutions must undergo screening and refinement through engineering judgment. However, such engineering judgment is precisely the core competency that structural design courses should cultivate. This framework establishes the fundamental logic for curriculum restructuring. AI handles the tasks of solution generation and preliminary screening, while the curriculum focuses on cultivating training capabilities and decision-making reasoning skills. This division of labor is not only about enhancing efficiency, but rather representing a fundamental shift in the pedagogical focus.

2.3. Clear Direction Within The Policy Framework

In 2026, the "AI + Education" Action Plan, jointly issued by the Ministry of Education and four other government departments, provided a policy foundation for this transformation. The document explicitly calls for optimizing talent training programs in traditional academic disciplines, facilitating the upgrading and transformation of traditional vocational education programs, and scientifically designing AI-integrated professional, curricular, and instructional frameworks. At the level of teaching methodology, the document proposes exploring human-machine collaborative teaching models, constructing immersive teaching environments, guiding students to develop critical thinking skills, and fostering the competencies necessary for the intelligent era. The exploration of human-machine collaborative paradigms and the cultivation of core competencies in the intelligent era have jointly delineated the fundamental direction for AI-integrated reform in courses such as mechanical equipment structural design courses that emphasize practical application and critical thinking training. This approach also provides clear policy foundations and actionable guidelines for us to undertake curriculum restructuring.

3. The Theoretical Framework and Core Principles of Reconstruction

3.1. Core Proposition: From Design Capability to Judgment Capability

The objective of the traditional structural design course can be summarized as equipping students with the capability to undertake simple mechanical structural designs. It is based on the underlying assumption that students should be able to independently complete the entire process from conceptualization to structural detailing. In AI-enabled design environments, this assumption requires re-examination. When AI can rapidly generate structural designs, students need to develop not so much the ability to generate designs, but rather the ability to evaluate them. This evaluative

capability includes: identifying potential failure paths within structural designs, assessing the degree to which design constraints are met, comparing the relative merits and trade-offs of different designs, and detecting apparent strengths in AI-generated designs that may actually harbor flaws. A research framework explicitly positions AI as an explanatory scaffold rather than a numerical solver, requiring students to validate AI-generated claims within a computational environment and assess their consistency with expected mechanical trends. The key insight from this approach is that structural design courses should transform AI from a mere solution provider to a source for selecting training materials.

3.2. Structural Design Principles

First, the principle of prioritizing judgment. All course design should aim to cultivate structural design judgment as its primary objective. The transmission of knowledge and the training of tools should serve this objective, rather than the opposite. This entails reducing diagram-based copying exercises and increasing tasks focused on scheme evaluation and defect diagnosis. Second, process-driven principle. The evaluation of design structuring competence should focus on the process rather than the outcome. The process evidence of students' design notes, iterative design records, correction logs of AI-generated outputs, and justifications for their decisions better reflect the development of their judgmental capabilities than final drawings. Some research emphasizes shifting from seeking answers to exploring behavior, that is, students no longer merely calculate whether a design satisfies given constraints, but instead explore how the degree of compliance evolves under varying parameters. Third, the principle of transparency in human-AI collaboration. Courses should require students to clearly document the ways and extent to which AI is involved in the structural design process of what AI generated, what corrections students made, and the rationale behind those corrections. Such transparency not only safeguards academic integrity but also serves as an effective means of fostering critical AI literacy.

4. Reorganization of The Course Content Framework for Mechanical Equipment Structural Design Course

4.1. Redistribution of Content Modules

Traditional structural design courses are typically organized by component type, such as shaft assemblies, housing structures, connection structures, and sealing structures. While this organizational approach provides a logical framework for knowledge transmission, it does not foster the systematic development of judgment skills. The content of the restructured course can be divided into three levels:

Level 1: Principles of structural design and failure awareness. This level addresses the fundamental question of why a particular design approach is adopted. Core content includes: common failure modes in structural design, such as fatigue failure, interference fit failure, sealing leakage, and assembly interference along with their underlying mechanisms, and identification of constraint conditions and determination of their priority, and evaluation criteria for structural design options, including functional adequacy, manufacturability, assembly ease, and maintainability. Instruction at this level should extensively employ diagnostic analysis of failure cases, rather than mere replication of successful designs.

Level 2: Methodology for AI-enabled structural design. This is a newly added methodology module, encompassing the following content: strategies for leveraging generative AI in structural design conceptualization, such as how to articulate functional requirements, how to define constraints, and how to filter generated outcomes, and the application of parametric modeling and

intelligent review tools, and systematic approaches for validating AI-generated outputs. The key objective is to establish metacognitive awareness of what AI can and cannot accomplish, as well as how to validate its outputs.

Level 3: Integrated structural design project. Using a real-world mechanical equipment structural design task as the foundation, this project requires students to complete the full workflow, including requirement analysis, AI-assisted solution generation, solution comparison and selection, structural refinement, and design validation. The project should incorporate deliberately designed pitfalls or ambiguous scenarios to expose students to the common constraint conflicts and trade-offs encountered in real-world structural design practices.

4.2. Selection and Usage Constraints for AI Tools

When introducing AI tools into the mechanical equipment structural design course, it is essential to clearly define what to use and how to use them.

During the solution generation phase, text generation models (e.g., Deepseek and Doubao) or image generation models can be utilized to assist in structural conceptualization. However, this must be complemented by a critique-and-refinement process: students first independently evaluate the AI-generated solution, then engage in discussions with their group members and the instructor, and finally develop a revised solution while documenting the rationale for the revisions. During the structural review phase, AI tools can be utilized to assist in checking assembly interference, the selection of standard parts, and other related issues. However, it is important to note that students must independently verify the results of the AI review. Some studies have required that, when an AI-generated statement conflicts with the computational results, students document the discrepancy and explain how their understanding has been altered as a result—such institutionalized verification practices can effectively prevent cognitive inertia. During the parametric design phase of course instruction, instructors can proactively introduce convenient and efficient scripted design calculation tools. Simultaneously, they can guide students to perform hands-on operations, allowing them to intuitively observe the dynamic evolution of the overall structural design by adjusting various parameters. Compared to the static presentation and explanation of design solutions common in traditional classrooms, this participatory, exploratory learning approach enables students to develop greater sensitivity to structural constraints and deepen their understanding of parametric design logic.

4.3. Alignment with Industrial Practice

The practical application of structural design courses is highly pronounced. The course content should be closely aligned with industrial practice. Research has indicated that the disconnect between theory and practice in the current training of mechanical design professionals is a prominent issue. College curricula tend to emphasize fundamental theories and classic design methodologies, yet these curricula often lack sufficient integration with practical engineering considerations, such as industry standards, specific process constraints, cost control, and modern design workflows.

Empowering and redefining existing structural design courses through AI technology entails leveraging the technical capabilities of AI to bridge the gap between theoretical instruction and industrial practice, thereby ensuring that the talent cultivated aligns more closely with the actual demands of the industry. For instance, by harnessing AI's resource integration capabilities, we can incorporate a wide array of real-world failed design cases from enterprises into the core materials of daily teaching. Furthermore, by leveraging AI to integrate with the full suite of structural design tools commonly used in industry, students can familiarize themselves with industry-standard

CAD/CAE integrated development environments while acquiring hands-on practical skills within an academic setting. Additionally, by utilizing AI's remote collaboration capabilities, engineers can participate in the review of student design projects, providing students with direct, practice-based professional critiques and actionable feedback for improvement.

5. Innovation in Teaching Models for the Mechanical Equipment Structural Design Course

5.1. Three-Stage Integrated Classroom Structure

A research has proposed a three-stage synergistic framework comprising intelligent pre-learning, collaborative inquiry, and targeted tutoring. This framework can be tailored to the specific characteristics of structural design courses. Pre-class intelligent pre-learning: Students utilize an AI assistant to acquire foundational knowledge of structural design concepts and preview relevant case studies. The AI assistant's role is not to deliver knowledge directly, but rather to pose guiding questions. For example, after presenting a structural design solution, the AI may ask whether the design remain valid if the load direction were changed. Thereby students can be encouraged to engage in preliminary critical thinking. Collaborative inquiry during class: Classroom time is primarily allocated to evaluating proposals and conducting decision-making discussions. The instructor presents a structural design scenario.Students then work in groups to generate alternative proposals using AI, followed by a critical analysis. The focus of the discussion is not which proposal is correct, but rather what the applicable conditions and potential risks of each proposal are. Post-class targeted tutoring: AI generates personalized case analyses and judgment training tasks based on students' classroom performance. Teachers provide focused explanations on common issues and offer in-depth guidance to address individual students' misconceptions.

5.2. Structural Design Alignment for Project-based Learning

Project-based learning has already been widely adopted in engineering courses. However, in structural design courses, project design requires particular attention to the implementation of judgment training.

By employing an AI-based auxiliary system for mechanical equipment structural design, this approach leverages the innovative integration of a local knowledge base and a workflow engine to address challenges such as spatiotemporal asynchrony, insufficient guidance, and fragmented knowledge. In this design course, AI can serve as both a reviewer of design specifications and a reminder of common errors. Crucially, the AI's feedback should be suggestive rather than evaluative. It should indicate where potential issues may arise, while leaving it to the student to determine whether such issues actually exist and how to resolve them.

5.3. Integrated Virtual-Real Mechanical Structural Cognitive Training

The development of students' capabilities in mechanical equipment structural design requires extensive hands-on practice, such as observing structures, disassembling them, and assembling them. The advent of AI technology can effectively complement such physical teaching methods, which are often constrained by practical conditions. By integrating AI with virtual simulation technologies, students can independently complete the entire learning cycle, from mechanical structural design to assembly verification, within a pre-configured virtual environment. The system utilizes AI to assist in identifying interference issues during the assembly process, as well as hidden process conflicts within design schemes, providing timely feedback to students. This trial-and-error, feedback, and correction learning loop can be repeatedly executed in a virtual environment at

minimal cost. It eliminates the consumption of physical materials and the need for additional physical space. Through prolonged practice, students can rapidly develop an intuitive understanding of the constraints inherent to various mechanical structures, thereby substantially enhancing their structural design capabilities.

6. Reconstruction of the Course Evaluation Mechanism

6.1. The Evaluative Value of Process Evidence

Mechanical equipment design is a gradual, step-by-step process characterized by progressive accumulation. Such capabilities are difficult to accurately and comprehensively assess through a single task or a conventional examination. Consequently, the evaluation of design capabilities should shift from a traditional outcome-oriented approach to one that focuses on capturing and assessing process-based evidence of capability development.

Specifically, student evaluations should encompass the following four aspects: 1) AI-assisted design journal: a comprehensive record of all initial design content generated by AI, as well as every adjustment and correction the student implements based on the AI-generated solution. 2) Solution comparison analysis report: requiring the student to conduct a systematic comparative analysis of at least two distinct initial design proposals generated by AI, across multiple dimensions including functionality, cost, and stability. 3) Decision rationale documentation: requiring the student to clearly articulate the specific justifications and supporting evidence underlying each key structural decision made during the design process. 4) Defect diagnosis report: requiring the student to comprehensively identify and analyze potential failure paths for a given structural design proposal.

6.2. Construction of Multi-criteria Evaluation Indicators

Evaluation criteria should shift from assessing the accuracy of drawings to evaluating quality. The following dimensions may be considered: 1) Constraint Identification Completeness: Does the student identify the key constraints in the design task? Are any critical constraints overlooked? 2) AI Output Criticality: Does the student detect issues in the AI-generated solution? Are the corrections appropriate? 3) Solution Comparison Systematicity: Does the comparison of different solutions cover the primary evaluation dimensions? 4) Decision-Making Reasoning Logic: Are the justifications for key structural decisions clear and well-supported?

AI can undertake certain automated tasks during evaluations, such as checking the compliance of drawings, verifying parameters of standard components, and detecting obvious assembly conflicts. However, evaluations involving the innovativeness of design solutions, the rationality of judgments, and the logical soundness of arguments must be led by instructors.

Self-evaluations should also be incorporated into the evaluation framework. During the reflective phase of their design process, students should review their design workflow, analyzing which judgments are accurate, which contained deviations, and what the underlying causes of those deviations are. This also serves as a crucial mechanism for developing their judgment skills.

7. Conclusion

By leveraging AI technology to reconstruct the teaching and assessment of the mechanical equipment structural design course, the teachers are required to achieve a fundamental conceptual shift: transitioning from teaching students how to perform design tasks to teaching them how to evaluate designs. At the content level, a three-tier framework comprising failure awareness,

methodology, and integrated projects should be established. At the methodological level, a synergistic workflow consisting of pre-learning, exploration, and guided practice should be developed. At the assessment level, a diversified evaluation system centered on process-based evidence and qualitative judgment should be constructed. The structural design course has long been regarded as the most challenging component of mechanical design instruction. The AI era may present a pivotal opportunity to transform this challenge, by shifting the primary difficulty from drafting and memorization to critical thinking and judgment. This latter challenge represents the true objective that engineering education should strive to achieve.

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