Under the Background of New Engineering, a Review of the Research Thread on the Optimization of Mechanical Engineering Curriculum System

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Abstract: *The New Engineering construction has introduced new requirements for the mechanical engineering curriculum system, namely the cultivation of interdisciplinary integration and complex engineering capabilities. Systematically reviewing the research thread in this field holds significant academic value. This paper conducts its analysis from three dimensions: the logical starting point, the core research themes, and the evolutionary trends. First, it identifies the shaping effect of New Engineering characteristics on curriculum forms, the structural redundancy and functional deficiency of the traditional system, as well as the multi-dimensional optimization constraints. Then, it focuses on the interdisciplinary integration of curriculum content, the design of topological relationships for progressive competency-based modules, and the integration and sharing mechanism for multi-source heterogeneous curriculum resources. Finally, it reveals the shift in research perspective from element adjustment to structural reshaping, the characteristics of thematic clustering and co-occurrence networks, as well as the paths of frontier emergence. This study provides a systematic knowledge framework and methodological reference for the optimization of the mechanical engineering curriculum system.*

Keywords: *New Engineering; Mechanical Engineering; Curriculum System Optimization; Research Thread; Interdisciplinary Integration*

Introduction

The optimization of the mechanical engineering curriculum system stands as one of the core issues in engineering education reform under the background of New Engineering. When the traditional curriculum system, which takes single-disciplinary knowledge organization as its main thread, confronts the infiltration of emerging technologies such as intelligent manufacturing, robotics, and the industrial Internet of Things, it reveals problems of structural redundancy, functional deficiency, and a lagging response to the external technology ecosystem. Systematically reviewing the research thread in this field helps to clarify the logical starting point of optimization, identify core research themes, and grasp evolutionary trends, thereby providing a theoretical basis for the reconstruction of the curriculum system. This paper starts with the shaping of curriculum forms and the identification of constraint conditions, analyzes themes such as interdisciplinary integration and modular topological design, and then explores the shift in research perspective and the directions of frontier breakthroughs, in order to provide a structured knowledge integration for research on the optimization of the mechanical engineering curriculum system.

1. The Logical Starting Point of the Optimization of the Mechanical Engineering Curriculum System Driven by New Engineering

1.1 The Shaping Effect of New Engineering Characteristics on the Curriculum Forms of Mechanical Engineering

The characteristics advocated by New Engineering, such as interdisciplinary integration, rapid iteration of industrial technologies, and the orientation toward complex engineering problems, are redefining the existing forms of the mechanical engineering curriculum. The traditional curriculum structure, which takes single-disciplinary mechanical principles, mechanics, and manufacturing processes as its main backbone, is gradually transforming into a composite curriculum form embedded with modules such as intelligent control, sensor detection, and data-driven approaches. This shaping process manifests itself in the shift of curriculum objectives from knowledge transmission to the cultivation of systems thinking and integration capabilities, as well as the evolution of curriculum content from static knowledge units to dynamically updated technology clusters. The evolution of curriculum forms is not a linear substitution; instead, while retaining the core mechanical foundation, it forms a new curriculum structure characterized by the coexistence of hierarchy and network through the addition of interdisciplinary knowledge nodes and the reorganization of curriculum presentation methods.

Specifically, the characteristics of New Engineering drive the expansion of the mechanical engineering curriculum from a "product design and manufacturing" orientation to a "product-service-system" full lifecycle orientation. For example, emerging knowledge domains such as robotics, the industrial Internet of Things, and digital twins are embedded into traditional mechanical design courses, thereby blurring the boundaries of the curriculum. The shaping of curriculum forms is also reflected in the teaching organization methods, where the proportion of project-based and problem-oriented course modules increases to meet the requirements of New Engineering for the ability to understand and reconstruct complex engineering systems. This process requires the curriculum form to be reconfigurable, allowing for the dynamic adjustment of the combination relationships among knowledge units according to technological frontiers, thus maintaining the adaptability and forward-looking nature of the curriculum system[1].

1.2 Analysis of Structural Redundancy and Functional Deficiency in the Traditional Curriculum System

The traditional mechanical engineering curriculum system has formed a knowledge chain with mechanics, materials, mechanical design, manufacturing processes, and control theory as its core elements during long-term operation, and this structure demonstrates strong adaptability during the stage of industrialized mass production. However, when facing the requirements of integration and intelligence proposed by New Engineering, this structure reveals obvious redundancy characteristics. On the one hand, some basic course contents reappear repeatedly across different courses; for example, the force analysis modules in engineering mechanics and mechanical principles have overlapping parts. On the other hand, certain outdated processing techniques and isolated technical details occupy considerable teaching hours without forming effective connections with cutting-edge technologies (such as additive manufacturing and intelligent maintenance). Structural redundancy not only reduces teaching efficiency but also crowds out the space for cultivating interdisciplinary knowledge and system integration capabilities.

Accompanying the redundancy is functional deficiency, which refers to the gaps in several key capability cultivation dimensions within the traditional curriculum system. Typical deficiencies include the systematic training of modeling and simulation capabilities for complex mechatronic systems, the curricular support for multi-source heterogeneous information fusion and decision-making capabilities, and the cultivation of modular design thinking oriented toward open architectures. Existing courses are mostly organized according to the logic of independent disciplines, lacking horizontally integrated courses or thematic modules, which makes it difficult for students to form a holistic cognitive framework when facing cross-domain technological integration. This functional deficiency is essentially a manifestation of the lagging response of the curriculum system to the technological logic of New Engineering, and its root cause lies in the path dependence resulting from the combined effect of the curriculum update mechanism and disciplinary barriers.

1.3 Identification of Multi-Dimensional Optimization Constraints for the Curriculum System

The optimization of the curriculum system does not occur in a vacuum; instead, it is jointly constrained by multiple dimensions of constraints. The first is the constraint of knowledge structure. The core foundations of mechanical engineering (such as statics, dynamics, material properties, and tolerance fits) are irreplaceable, and the optimization process must maintain sufficient course hours and depth to ensure the professional foundation. The second is the hard constraint of course hour resources. Under the premise that the total credits are basically fixed, any new module inevitably requires the deletion or restructuring of existing content, which leads to a configuration trade-off between core knowledge and emerging knowledge. The third is the constraint of the logical sequence of courses. Strict prerequisite-subsequent relationships exist among mechanical engineering courses; for example, theoretical mechanics is a prerequisite for mechanical principles, and mechanical principles is a prerequisite for mechanical design. The optimization plan must respect this cognitive progression rule; otherwise, it may result in a broken learning path[2].

In addition to the above internal constraints, there also exist constraints from the external technology ecosystem. The industry's demand for the capabilities of mechanical engineering graduates shows a dynamic evolution trend, and the penetration rates of technologies such as industrial robots, intelligent sensing, and edge computing increase year by year, forcing the curriculum system to seek a dynamic balance between stability and renewal. Equipment and laboratory conditions also pose practical constraints on curriculum optimization; the lack of certain high-end experimental teaching resources (such as multi-degree-of-freedom motion platforms and real-time simulation systems) limits the feasibility of the corresponding course modules. The knowledge structure of the teaching faculty also constitutes a soft constraint; the effective offering of interdisciplinary courses depends on the instructors' own mastery of emerging technologies, which often needs to be alleviated through faculty training or team restructuring. Identifying and analyzing these multi-dimensional constraints serves as a prerequisite for formulating a feasible optimization path.

2. Core Research Themes in the Optimization of the Mechanical Engineering Curriculum System

2.1 Interdisciplinary Integration of Curriculum Content and Reconstruction of Knowledge Boundaries

Interdisciplinary integration stands as one of the core issues in the optimization of the mechanical engineering curriculum system. Its essence lies in breaking the knowledge silos within the mechanical engineering discipline and embedding the core concepts and methods of adjacent disciplines such as control, information, materials, and optics into the knowledge map of the mechanical curriculum. The integration process is not a simple superposition of knowledge points from multiple disciplines; instead, it forms composite knowledge modules with functional coupling characteristics by identifying the logical connections among knowledge units from different disciplines. For example, introducing the principles of sensing signal processing and actuator driving into the mechanical design course establishes a correspondence between the traditional design process and the perception-decision-action closed loop. Interdisciplinary integration also triggers the reconstruction of knowledge boundaries. The core knowledge originally belonging to the mechanical field (such as tolerance fits and kinematic chain analysis) needs to re-demarcate hierarchical relationships with the newly introduced interdisciplinary knowledge, clarifying which parts serve as the fundamental core, which serve as expansion interfaces, and which serve as elective in-depth directions.

Another dimension of knowledge boundary reconstruction is reflected in the rebalancing between the cutting-edge nature and the classical nature of curriculum content. As technologies such as artificial intelligence, edge computing, and digital twins penetrate mechanical engineering, certain low-frequency calculation methods and manual operation skills in traditional mechanical courses face compression or relocation to the status of auxiliary reference materials. The movement of knowledge boundaries is not a one-way expansion; it also includes the pruning of outdated or redundant content. The reconstruction process requires the establishment of a weight evaluation model for knowledge units, using indicators such as technological maturity, frequency of industrial application, and strength of capability support to determine the retention priority of each knowledge unit. Interdisciplinary integration and knowledge boundary reconstruction jointly drive the evolution of the mechanical curriculum from a rigid, closed structure to a flexible, open structure, thereby providing the content foundation for the subsequent topological design of course modules.

2.2 Topological Relationship Design of Progressive Competency-Based Course Modules

The design of progressive competency-based course modules focuses on students' gradual improvement at the three levels of cognition, analysis, and synthesis, and its topological relationship determines the effectiveness of the learning path and the distribution of the learning load. The topological relationship design needs to treat course modules as nodes and prerequisite-subsequent relationships as directed edges, thereby constructing an acyclic and well-reachable course network. In the context of mechanical engineering, the basic modules (such as engineering graphics and theoretical mechanics) are located at the front end of the topological structure, the intermediate modules (such as mechanical principles, mechanical design, and interchangeability measurement) are located in the middle, and the advanced integration modules (such as mechatronic system design, robotics, and intelligent manufacturing systems) are located at the back end. Progressive competency requires a clear cognitive gradient between adjacent levels, with each subsequent module introducing a new dimension of complexity based on the knowledge foundation established by the preceding module, for example, transitioning from the kinematic analysis of a single mechanism to the coordinated control of multiple mechanisms, and then to the behavior prediction of the entire system[3].

The topological relationship design also needs to handle the relationship between parallel paths and cross paths. Different competency dimensions (such as analytical ability, design ability, and experimental ability) may correspond to parallel module chains, and these chains need to converge at appropriate nodes to form comprehensive competency training points. For example, the control engineering module and the mechanical vibration module converge at the node of system dynamics simulation, requiring students to simultaneously draw on knowledge from both directions. The key nodes in the topological structure (i.e., courses where multiple prerequisite modules converge) often correspond to critical stages of competency leap, and the class hour allocation and teaching organization format at these nodes require special design. The quality of progressive competency-based topological relationships can be quantitatively evaluated through indicators such as the redundancy of the learning path, the length of the critical path, and the degree of module coupling, thereby providing a structural basis for the optimization of the curriculum system.

2.3 Multi-Source Heterogeneous Integration and Sharing Mechanism of Curriculum Resources

The multi-source heterogeneous nature of curriculum resources derives from the broad range of knowledge domains involved in the content of mechanical engineering courses, which includes theoretical teaching resources (textbooks, courseware, and exercise banks), experimental resources (hardware equipment, virtual simulation platforms, and testing instruments), computational resources (CAD/CAE/CAM software, code libraries, and datasets), and case resources (engineering drawings, process documents, and fault reports). These resources exhibit significant differences in format specifications, storage locations, access permissions, and update frequencies, thereby constituting heterogeneity. The integration of these resources requires the establishment of a unified metadata description framework, allowing resources from different sources to be linked and retrieved according to the knowledge point indices of the course modules. For example, it performs semantic association among the theoretical derivation, simulation model files, experimental operation videos, and typical fault cases corresponding to a specific knowledge point of gear transmission design, thereby forming a multimodal resource package for that knowledge unit.

The construction of the sharing mechanism aims to improve resource utilization efficiency and reduce the implementation cost of curriculum optimization. Within the mechanical engineering curriculum system, different courses have demands for resource reuse; for example, the mechanical design course and the mechanical manufacturing course share the same set of three-dimensional model libraries, and the robotics course and the sensor course share the same set of data acquisition platforms. The sharing mechanism requires the design of resource access protocols and version control strategies to avoid redundant construction and data inconsistency caused by resource dispersion. A resource pooling solution based on a network platform enables centralized storage and on-demand access to resources, while also supporting a contribution-evaluation-iteration closed loop for resources. The sharing mechanism also involves the issue of resource quality maintenance, including regular reviews, updating of obsolete content, and supplementing resource modules corresponding to cutting-edge technologies. The establishment of the multi-source heterogeneous integration and sharing mechanism serves as a key support for moving the optimization of the curriculum system from scheme design to operable implementation.

3. Research Thread and Evolutionary Trends in the Optimization of the Mechanical Engineering Curriculum System

3.1 The Migration of the Research Perspective from Element Adjustment to Structural Reshaping

Early research on the optimization of the mechanical engineering curriculum system mostly focused on the adjustment of local elements, such as the updating of content in a single course, the increase or decrease of class hours for a particular teaching segment, or the replacement of specific experimental equipment. This type of research regarded the curriculum system as a relatively stable framework, and the optimization activities were mainly manifested as the repair and replacement of components within the framework. With the penetration of the New Engineering concept, the research perspective has gradually risen from the element level to the structural level, focusing on the overall organizational logic and operational mechanism of the curriculum system. Structural reshaping emphasizes the strength of connections among course modules, the paths of information transmission, and the emergent properties of the overall function, rather than the judgment of the quality of isolated modules. This migration is reflected methodologically in the shift from linear additive thinking to systemic topological thinking, and researchers have begun to use methods such as network analysis and graph theory to describe the connectivity and robustness of the curriculum system.

The rise of the structural reshaping perspective is also closely related to the increased requirements for cultivating complex engineering system capabilities in the mechanical engineering field. Improvements to a single course or a single knowledge point make it difficult to support students in forming cross-domain integration capabilities; instead, it is necessary to change the internal structure of the system by adjusting the hierarchical relationships among courses, restructuring the prerequisite-subsequent chains, and establishing horizontal integration channels. The migration of the research perspective is also reflected in the transformation of optimization objectives, shifting from the pursuit of completeness of knowledge coverage to the pursuit of smoothness in capability generation, and from reducing content redundancy to eliminating cognitive gaps. Current research is no longer satisfied with identifying which courses need to be added or removed; instead, it asks what structural organization of the curriculum system can more efficiently map external technological demands into internal capability outputs. This perspective migration constitutes the logical main thread of the evolution of the entire research thread[4].

3.2 Thematic Clustering and Co-occurrence Network Characteristics of Research Hotspots

Through the keyword co-occurrence analysis of the literature in the field of optimization of the mechanical engineering curriculum system, researchers can identify several stable thematic clusters. The first cluster revolves around "interdisciplinary integration" and includes keywords such as intelligent manufacturing, robotics, the Internet of Things, and embedded systems. These terms frequently co-occur with traditional course names such as mechanical design and mechanical manufacturing, reflecting the research popularity of curriculum content integration. The second cluster focuses on "competency orientation" and involves terms such as engineering systems thinking, innovative design ability, and complex problem solving. The research in this cluster concerns how course modules support the transformation from knowledge acquisition to competency application. The third cluster is related to "digitalization of curriculum resources" and includes keywords such as virtual simulation, open online courses, and digital twin teaching, pointing to the supporting role of the morphological transformation of teaching resources in the optimization of the curriculum system.

The structural characteristics of the co-occurrence network reveal the intrinsic connection strengths and mediating nodes among research themes. Traditional core courses such as mechanical principles and mechanical design occupy high centrality positions within the entire network, and they have strong connections with each emerging thematic cluster, indicating that traditional courses remain the anchor of optimization rather than the object of replacement. Control engineering and sensor technology are located at the intersection of the interdisciplinary integration cluster and the competency-oriented cluster, and they serve as a bridging function for knowledge fusion and competency generation. The time-slice analysis of the co-occurrence network shows that the early network took the independent adjustment of courses as its theme, and connections among nodes were sparse; the middle stage saw the emergence of a locally dense subgraph centered on mechatronic system integration; the recent network presents a pattern of highly interconnected multiple clusters, and isolated nodes have decreased significantly. This network evolution characteristic confirms the overall migration trend of the research perspective from element adjustment to structural reshaping.

3.3 The Emergence Paths of Research Frontiers and Potential Breakthrough Directions

The identification of research frontiers relies on the analysis of highly cited literature, burst keywords, and conceptual aggregation in newly published literature. Currently, the emergence paths of frontiers in the field of optimization of the mechanical engineering curriculum system mainly manifest themselves in three paths. The first path extends from the integration of curriculum content to the construction of the curriculum ecosystem. Researchers are no longer satisfied with incorporating interdisciplinary knowledge into the curriculum; instead, they attempt to design an adaptive and self-adjusting curriculum ecosystem framework that enables the curriculum system to perform self-organizing updates based on signals of technological replacement. The second path moves from the design of progressive competency modules to the modeling of cognitive load distribution. By means of learning analytics and educational data mining, it quantitatively characterizes the patterns of consumption of students' cognitive resources by different course sequences, thereby optimizing the ordering and spacing of modules. The third path focuses on the evaluation methods for the effectiveness of curriculum system optimization. Traditional satisfaction surveys and grade comparisons are being replaced by multi-dimensional evaluation frameworks based on competency rubrics and knowledge graph coverage rates.

Potential breakthrough directions include the formal description and computable modeling of the curriculum system. Most current optimization studies still rely on expert experience and qualitative judgments, and they lack mathematical models that can support the simulation and deduction of optimization schemes. Constructing an optimization model of the curriculum system that includes knowledge units, competency indicators, constraint conditions, and objective functions will make the comparison and selection of different optimization strategies reproducible and verifiable. Another breakthrough direction lies in the research on mapping and transformation mechanisms between heterogeneous curriculum systems, that is, how to provide differentiated optimization paths for the curriculum system to higher education institutions of different levels and types while maintaining the output of core competencies. The advancement of frontier research will drive the optimization of the mechanical engineering curriculum system from an experience-driven stage to a new stage jointly driven by data and models.

Conclusion

This paper systematically reviews the research progress on the optimization of the mechanical engineering curriculum system under the background of New Engineering from three levels: the logical starting point, the core research themes, and the research thread. The research perspective has shifted from local element adjustment to overall structural reshaping. The integration of curriculum content and the design of progressive competency-based modules have become core concerns, and the integration and sharing mechanism for multi-source heterogeneous curriculum resources is gradually becoming operationalizable. Future directions include the construction of a formal description and computable model of the curriculum system to enable the simulation, deduction, comparison, and verification of different optimization strategies; the exploration of mapping and transformation mechanisms between heterogeneous curriculum systems to provide differentiated optimization paths for different types of institutions; and the introduction of learning analytics and cognitive load modeling methods to quantify the patterns of influence of course sequences on students' cognitive resources, thereby driving the optimization of the curriculum system from an experience-driven stage to a stage jointly driven by data and models.

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