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: *With the development of new engineering construction, new demands have arisen for the system of mechanical engineering courses, namely the cultivation of interdisciplinary integration and complex engineering ability. Organise a study of the research thread in this area to learn from it. The three parts of the analysis in this paper are the logical basis, the main research content and the development trend. First, consider how the features of the New Engineering will affect the form of the curriculum, as well as structural redundancy and functional deficiency in the traditional system, and all other optimisation constraints. Next, we will present the interdisciplinary integration of curriculum content, design the topology for progressive competency-based modules, and discuss the integration and sharing mechanism of multi-source heterogeneous curriculum resources. Finally, it can be seen that the direction of research has shifted from element adjustment to structural reshaping, then to the characteristics of thematic clustering and co-occurrence networks, and finally to the paths of frontier emergence. Organisation of Knowledge and Methods for Improving the System of Mechanical Engineering Education are introduced in this paper.*

Keywords: *New Engineering, Mechanical Engineering, Optimisation of Curriculum System, Research Thread, Interdisciplinary Integration*

Introduction

Optimisation of the mechanical engineering curriculum system is one of the main problems in the reform of engineering education under the New Engineering. When the traditional curriculum system, which is based on the organisation of knowledge in a single subject, is affected by the infiltration of new technologies such as intelligent manufacturing, robotics and the industrial Internet of Things, it will have problems of structural redundancy, functional deficiency and slow response to changes in the external technology ecosystem. A systematic review of the research thread in this area will be carried out to clarify the logical starting point for optimisation, identify the main research topics, understand the evolutionary trend, and thus provide a theoretical basis for the reconstruction of the curriculum system. First, this paper will list the types of curriculum forms and identify the constraint conditions; next, it will introduce themes such as interdisciplinary integration and modular topological design; finally, it will discuss changes in research perspectives and directions for frontier breakthroughs to provide an organised knowledge integration foundation for research on the optimisation 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

With the changes in New Engineering, such as cross-disciplinary integration, the rapid development of industrial technology and more serious engineering problems, the traditional form of the mechanical engineering curriculum is changing. The original structure of the curriculum was a single subject organised mechanically, focused on mechanics and manufacturing processes, but now it is gradually changing into a comprehensive curriculum with many parts, such as intelligent control, sensor detection, data-driven methods, etc. The formation process can be shown by the change in curriculum goals from the transmission of knowledge to the cultivation of systems thinking and integration ability, as well as by the change in curriculum content from fixed units of knowledge to dynamic technology clusters. The development of curriculum forms is not a simple replacement; rather, in keeping with the basic mechanical foundation, a new curriculum structure has been established that is both hierarchical and network-like by adding interdisciplinary knowledge nodes and altering the presentation method of the curriculum.

With the development of New Engineering, the content of the mechanical engineering curriculum has been expanded from "product design and production" to cover the entire life cycle of "product-service-system". New areas of knowledge, such as robotics, the industrial Internet of Things and digital twins, have now been added to the traditional curriculum of mechanical design, and thus the boundaries of the curriculum have been blurred. The construction of curriculum forms can also be seen in the organisation mode of teaching, and to meet the demands of New Engineering for the ability to understand and reconstruct complex engineering systems, the proportion of project-based and problem-oriented course modules has been increased. Therefore, the form of the curriculum should be flexible and adaptable; with the development of technology, we can change how different modules of knowledge are connected to keep up with the times and meet educational needs[1].

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

Over a long period of time, the traditional chain of knowledge in the mechanical engineering curriculum system has been based on mechanics, materials, mechanical design, manufacturing processes and control theory, and this structure is very suitable for the era of industrialised mass production. Given the new demands for integration and intelligence in the era of new construction, the above structure is obviously outdated. On the one hand, some of the basic course content is repeated in various courses; for example, the force analysis module in Engineering Mechanics and Mechanical Principles has overlapping parts. At the same time, some old processing methods and isolated technical details are still in the curriculum and have not been linked with new technologies (such as additive manufacturing and intelligent maintenance). Structural redundancy is not conducive to teaching and may prevent the integration of all kinds of knowledge and system thinking.

In addition to being redundant, many of the necessary functions of education in the old curriculum system are also absent. The main deficiencies are that there is no organised training in modelling and simulation of complex mechatronic systems, the curriculum does not offer strong support for multi-source heterogeneous information fusion and decision-making, and there is a weak culture of modular Design Thinking based on open architectures. Most of the current courses are organised according to the logic of independent disciplines and lack horizontally integrated courses or thematic modules; thus, it is difficult for students to build an all-encompassing cognitive framework in the face of cross-domain technological integration. The root of the function deficiency is that the curriculum system has not been updated in time to meet the technological demands of New Engineering, and this is due to the path dependence created by the joint effect of the curriculum revision mechanism and disciplinary barriers.

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

Optimisation of the curriculum system has not happened in a vacuum, and it has also been affected by all sorts of other factors. The first is a problem of knowledge structure. The foundation of mechanical engineering (such as statics, dynamics, material properties and tolerance fits) needs to be laid, so the optimisation process should have enough course hours and depth to provide a solid professional basis. Second, there is a serious shortage of course-hour resources. Given that the total number of credits is fixed, when adding a new module, some of the old content must be deleted or rearranged; therefore, a trade-off has to be made between core knowledge and new knowledge. The third is that the order of the courses is not systematic. There are some prerequisites and necessary results for all the courses in mechanical engineering; for example, one must have taken theoretical mechanics before taking mechanical principles, and one needs to have studied mechanical principles before taking mechanical design. The optimisation plan should follow the rules of cognitive development; otherwise, it will be impossible to learn properly[2].

The reasons mentioned above are due to external factors in the technology ecosystem as well. The demands of the industry for the abilities of mechanical engineering graduates are changing at an unpredictable pace, and with the continuous development and application of technologies such as industrial robots, intelligent sensing and edge computing in daily life, the curriculum system needs to be adjusted accordingly. Other practical constraints on the optimisation of the curriculum include equipment and laboratory conditions; due to the lack of some high-end experimental teaching resources (such as multi-degree-of-freedom motion platforms and real-time simulation systems), the corresponding course modules cannot be added. Another kind of restriction is the knowledge structure of the teaching staff; in order to successfully offer interdisciplinary courses, teachers need to have mastered the new technologies themselves, so faculty training or team restructuring is often required to correct this deficiency. List all the constraints and determine if an optimisation problem needs to be solved.

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

2.1 Interdisciplinary Integration of Curriculum Content and Reconstruction of Knowledge Boundaries

The integration of all subjects is one of the main problems in the reform of the mechanical engineering curriculum system. To break down the silos of knowledge in the field of mechanical engineering, basic knowledge and technologies from related disciplines such as control, information, materials and optics should be added to the knowledge map of the mechanical engineering curriculum. Integration is not the collection of knowledge points from all places; rather, it is the construction of combined knowledge modules with functional coupling characteristics through the discovery of logical connections among knowledge units in different areas. For example, in the course of mechanical design, one can introduce the concepts of sensing signal processing and actuator driving to show how they are related to the traditional design process and the closed-loop system of perception-decision-action. Cooperation among schools will expand the scope of knowledge. The original core knowledge in the field of mechanics (such as tolerance fits and kinematic chain analysis) needs to be redefined in light of the newly added interdisciplinary knowledge; that is to say, determine which parts serve as the fundamental core, which function as expansion interfaces, and which are elective areas for in-depth study.

Another way to talk about the boundary of knowledge reconstruction is to determine whether the content of the curriculum is modern or traditional. With the development of artificial intelligence, edge computing and digital twins have reduced or changed some of the older, low-frequency calculation methods and manual operation skills taught in traditional mechanical engineering courses to the level of auxiliary reference materials. The movement of the boundary of knowledge is an extension, but it is also the elimination of old or redundant content. Build a weight evaluation model for knowledge units in the reconstruction process, and according to indices such as technological maturity, frequency of industrial application and strength of capability support, determine the retention priority of each knowledge unit. Integration of all kinds of knowledge systems and the expansion of the boundary of knowledge can provide an open and flexible foundation for the development of the mechanical curriculum, thus offering material support 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 aims to promote the continuous development of students at the three levels of cognition, analysis and synthesis, and the topology of these levels will determine the efficiency and distribution of the learning path and learning load. Design a Topology that is a Directed Acyclic Graph (DAG), set the course modules as nodes, and make the prerequisite-subsequent relationships directed edges; it should be well-connected. The first section of the modules in the field of mechanical engineering is the basic modules (such as engineering graphics and theoretical mechanics); the middle part consists of the intermediate modules (such as mechanical principles, mechanical design and interchangeability measurement); and the last part is the advanced integration modules (such as mechatronic system design, robotics and intelligent manufacturing systems). Progressive competency should have a clear cognitive gradient at different levels, and each new module should be based on the knowledge foundation provided by the previous module; for example, one might start with the kinematic analysis of a single mechanism, then move to coordinated control of multiple mechanisms, and finally study the behavior prediction of the whole system[3].

The Design of the topological relationship should also account for the connection of parallel paths and cross paths. All dimensions of competence (e.g., analytical ability, design ability, experimental ability) can be mapped to parallel chains of modules, and at various nodes in these chains, a general training point for all competencies is set up. For instance, at the node of the system dynamics simulation, the control engineering module and the mechanical vibration module meet, and one needs to use knowledge from both places at the same time. The main nodes in the topological structure, that is to say, the courses that many prerequisite modules are based on, are often critical points for competency jumps, so special attention should be paid to the allocation of class hours and teaching organisation for them. The quality of the progressive competency-based topological relationship can be expressed in terms of indicators such as the redundancy of the learning path, the length of the critical path and the degree of module coupling, etc., and thus, a structural basis for the optimisation of the curriculum system will be provided.

2.3 Multiple-source Heterogeneous Integration and Sharing Mechanism for Curriculum Resources

There are many kinds of curriculum resources, and because there are many areas of knowledge in the courses of mechanical engineering, they are very diverse; these include theoretical teaching materials (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 materials have various requirements for form, place of storage, rights of use and frequency of update, so they are very different. Based on the above resources, a single metadata description framework needs to be built to connect with and use resources from all places according to the knowledge-point indices of the course modules. For example, one can construct a semantic association among the theoretical derivation, simulation model files, experimental operation videos and typical fault cases of a particular knowledge point in gear transmission design to form a multimodal resource package for that unit of knowledge.

The goal of building a sharing system is to make better use of resources and reduce the costs of curriculum reform. The different courses in the system of mechanical engineering courses have various demands for resource reuse; for example, the mechanical design course and the mechanical manufacturing course can use the same set of three-dimensional model libraries, and the robotics course and the sensor course can use the same set of data acquisition platforms. A sharing mode will be set up, and at the same time, there will be no construction redundancy or data inconsistency caused by the dispersion of resources. A resource pool in the middle of a network platform organises the storage and on-demand utilisation of resources, and it is also a closed-loop system for the contribution, evaluation and optimisation of resources. Regularly change the distribution mode, update the quality of the resources, discard old materials, add new modules in line with changes in technology, etc. The first foundation for improving the optimisation of the curriculum system in the period from planning to implementation is to build a multi-source heterogeneous integration and sharing mechanism.

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

3.1 The Change in the Focus of Research from Element Adjustment to Structural Reshaping

The first studies to improve the system of mechanical engineering courses have mainly addressed deficiencies in local conditions by changing the content of a single course, increasing or decreasing the number of class hours for a particular part of the teaching, or substituting some experimental equipment. The first kind of study is based on the current curriculum system, and at the same time, it mainly focuses on correcting or improving the components of this system. With the spread of the New Engineering idea, the focus of research has gradually shifted from the level of elements to that of structure, and now it covers the whole organisational logic and working mode of the curriculum system. Structural Reorganisation is to strengthen the links among course modules, improve the flow of information, and what features the whole system will have, rather than enhancing the quality of individual modules. Therefore, there has been a shift in the research method from linear addition to systemic topology, and now network analysis and graph theory are used to explore the connections and stability of the curriculum system.

The appearance of the idea of structural rearrangement can be traced back to the increasing demand for the cultivation of the ability of complex engineering systems in the field of mechanical engineering.

Strengthening only one subject or a particular area of knowledge will not help the students develop the ability to integrate knowledge from all fields; instead, we need to adjust the internal structure of the system by modifying the hierarchy of courses, reorganising prerequisite-and-subsequent chains, and creating channels for horizontal integration. A change in the direction of research can also be inferred from changes in the optimisation goals; it is no longer about covering all the knowledge but gradually building abilities, and the aim has shifted from reducing content redundancy to eliminating cognitive gaps. Research has identified which courses need to be added or deleted, and at the same time, it has also been exploring how to build a curriculum system that can better turn external technological demands into internal strengths and achieve good results. The above view migration is the main reason for the development of the entire research line[4].

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

Based on the analysis of keyword co-occurrence in the literature on the optimisation of the mechanical engineering curriculum system, some stable thematic clusters have been identified. The first group is "interdisciplinary integration", and its keywords are intelligent manufacturing, robotics, the Internet of Things and embedded systems. These terms often appear together with the traditional course names "Mechanical Design" and "Mechanical Manufacturing", indicating that there is growing interest in combining the curriculum content. The second group is "competency orientation", and the following are engineering system thinking, innovative Design ability and complex problem-solving. Scholars have studied the impact of course modules on the dissemination of knowledge and skills. The third group is "digitalisation of curriculum resources", and its keywords are virtual simulation, open online courses and digital twin teaching; from this, we can see that the support role of the morphological transformation of teaching resources in optimising the curriculum system is being studied.

The structure of the co-occurrence network shows the strength of the connection among and mediation by the research themes. Traditional core courses, such as mechanical principles and mechanical design, are at the center of the entire network, have strong links with all emerging thematic clusters, and will therefore continue to be the foundation for optimisation rather than the objects of replacement. Control engineering and sensor technology are in the intersection of the cluster for interdisciplinary integration and the cluster for competency development, and they offer links for knowledge fusion and competency development. Time-slice analysis of the co-occurrence network shows that in the early stage, the theme was the independent adjustment of courses, and the connection among nodes was sparse; in the middle period, a locally dense subgraph centred on mechatronic system integration appeared; and in recent years, there has been a pattern of highly interconnected multiple clusters, and isolated nodes have decreased significantly. Therefore, it can be seen that the whole focus of the research has shifted from modifying elements to reorganising structure.

3.3 The Origin Paths of Research Frontiers and Possible Directions for Breakthroughs

The research front will be set in line with the analysis of highly cited papers, burst keywords and conceptual aggregation in newly published literature. At present, the development paths of frontiers in the field of optimisation for the mechanical engineering curriculum system are mainly taking three forms. The first is to integrate the curriculum with the construction of a curriculum ecosystem. Research is no longer about integrating knowledge from all parts of the school; instead, it aims to build an adaptive and self-regulating ecosystem framework for the curriculum that can adjust the entire curriculum system independently in light of changes in technology. The second way is to build graded competency modules and then model the distribution of cognitive load. Based on the results of learning analytics and educational data mining, we have learned how students use their cognitive resources in different ways during class and can better organise and distribute learning materials. The third is to determine how to assess the results of the reform in the curriculum system. The old way of collecting satisfaction information and grades is being replaced by many kinds of evaluations that consider abilities and knowledge bases.

One of the first is formalisation and computable modelling of the curriculum system. Most of the current optimisation research is still based on the experience and intuition of experts, and there are no mathematical models to support the simulation and deduction of optimisation schemes. Build an optimisation model of the curriculum system that contains knowledge units, competency indicators, constraint conditions and objective functions, and then run and verify the comparison and selection of various optimisation strategies. The other is to map and transform heterogeneous curriculum systems, that is, how to provide differentiated and optimised paths for the curriculum systems of higher education institutions at different levels and in different forms while keeping the output of core competencies. With the progress of frontier research, the optimisation of the mechanical engineering curriculum system will be data- and model-driven in the new era, based on the previous experience-driven stage.

Conclusion

Organise the research results on the optimisation of the mechanical engineering curriculum system in light of New Engineering in this paper systematically, and divide them into three parts: the logical starting point, the main research content and the research path. Next, we will consider the reasons for the problems and changes in the entire system. Now people are paying more attention to how to integrate curriculum content with the design of progressive competency-based modules, and the integration and sharing of multi-source heterogeneous curriculum resources are gradually being realised. In the future, with the development of an official description and a computable model of the curriculum system, all kinds of optimisation strategies based on simulation, deduction, comparison and verification can be employed. Mappings and transformations will be established among all the different curriculum systems to provide various optimisation paths for all kinds of institutions, and learning analytics and cognitive load modelling methods will be employed to quantify how course sequences affect students' cognitive resources; thus, the optimisation of the curriculum system will move from an experience-driven stage to a joint-data-model-driven one.

References

[1] Xu, P., et al. "Research on the Practical Path of Ideological and Political Education System for Mechanical Engineering Courses under the Background of New Engineering." China Machinery, no. 22 (2025): 147-151.

[2] Chen, J. W., et al. "Research on the Construction of a Demonstration Curriculum System for Ideological and Political Education in Mechatronic Engineering under the Background of New Engineering." Journal of Higher Education, vol. 11, no. 04 (2025): 91-95.

[3] Xiao, Z. Y. "Exploration of Curriculum System Reform for Mechanical Engineering Majors under the Background of New Engineering: Taking the Mold Design and Manufacturing Major as an Example." Science Consulting, no. 11 (2024): 200-204.

[4] Li, D. M., et al. "Construction and Implementation of the Curriculum System for Mechanical Design, Manufacturing and Automation Majors in Ethnic Universities under the Background of New Engineering." Journal of Higher Education, vol. 9, no. 25 (2023): 17-20.