An exploration of the reform of the classroom teaching mode for the mechanical engineering major is conducted

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Abstract: *The classroom teaching of the mechanical engineering major faces the dual challenges of cognitive overload and knowledge transmission distortion. These challenges are specifically manifested in the spatial mapping conflict between engineering graphics and manufacturing processes, the constraint of linear structures on the formation of systemic thinking, and the representational limitations in understanding dynamic mechanisms. Based on cognitive constructivism theory, this study proposes a restructuring of teaching logic: the introduction of modular reverse reasoning in the mechanical principles course, the implementation of spatial mapping and process visualization reconstruction in the manufacturing process course, and the application of constraint prioritization and decision node activation in mechanical design courses. Furthermore, this study establishes dynamic adjustment mechanisms such as cognitive load quantification and grading, attention curve alignment, and rhythm control. It also develops an adaptive path generation method based on a disciplinary knowledge graph, thereby providing an operable cognitive pathway for the reform of the teaching mode.*

Key words: *mechanical engineering major; classroom teaching mode; cognitive constructivism; reverse reasoning; knowledge graph; dynamic regulation*

Introduction

Mechanical engineering courses involve multiple types of heterogeneous information, such as spatial geometry, kinematics, and process parameters. The current linear lecturing and static diagrams fail to help students establish an integrated cognitive framework of function, structure, and behavior. The parallel arrangement of engineering graphics and manufacturing processes leads to cognitive switching loss. The loss of temporal dimension information in dynamic analysis results in a one-sided understanding of concepts such as dead points. The scattered distribution of design constraints across different chapters causes the delayed exposure of design errors. These contradictions reveal a deep mismatch between traditional teaching and the cognitive laws of the mechanical engineering discipline. Therefore, it is necessary to reshape the teaching logic from the perspective of cognitive constructivism and introduce dynamic adjustment mechanisms. Accordingly, exploring the reform of the teaching mode based on cognitive laws has clear theoretical necessity and practical relevance.

1. Cognitive Load and Knowledge Transmission Dilemmas in Mechanical Engineering Classroom Teaching

1.1 Dual Cognitive Obstacles in Engineering Graphics and Manufacturing Process Courses

The engineering graphics course requires learners to perform bidirectional conversion operations from three-dimensional entities to two-dimensional projection expressions and from two-dimensional graphics to three-dimensional spatial reconstruction. This process relies on the continuous engagement of visuospatial working memory. The manufacturing process course involves dynamic entity relationships such as cutting motions, tool geometries, fixture positioning, and process sequences. It requires students to simulate material removal processes and machine tool action sequences in their minds. When the two courses are offered in parallel during the same semester or adjacent semesters, students' cognitive systems need to switch frequently between the graphic symbol system and the process entity system. This switching not only consumes cognitive resources but also easily leads to mapping confusion. For example, students may mistake the unfolding direction of a projection plane for the feed direction of a process, thus forming a conceptual fixation that is difficult to correct.

1.2 The Constraint of Linear Teaching Structure on the Formation of Mechanical System Thinking

The current classroom teaching of the mechanical engineering major generally proceeds according to the chapter sequence, following a linear path of part design, mechanism motion, transmission system, and manufacturing process. This structure presents the knowledge points in a serial rather than a networked manner. When students learn the calculation of gear parameters, they find it difficult to simultaneously relate to the gear processing methods and inspection benchmarks in subsequent chapters. When they learn the design of shafting components, they lack the prior understanding of assembly sequences and manufacturability. The linear structure severs the inherent functional coupling relationships of mechanical systems. Although students can perform calculations or memorization for individual knowledge points, they struggle to construct a whole-machine-level functional transmission chain and constraint propagation path in their minds, thus delaying the formation of mechanical system thinking.

1.3 The Representational Limitations of the Traditional Lecture Mode in Understanding Dynamic Mechanisms

The traditional lecture mode relies on two-dimensional simplified diagrams in static boards, slides, or textbook illustrations to represent the kinematic relationships of mechanisms. For the variation patterns of the displacement, velocity, and acceleration of the follower with the cam angle in a cam mechanism, as well as the continuous generation process of the coupler curve in a four-bar linkage, static diagrams can only display several discrete positions and orientations. Even when the teacher supplements the diagrams with verbal descriptions, it is difficult for students to perceive the transitional motion and instantaneous velocity changes between adjacent positions and orientations. This mode of representation loses the continuous information in the time dimension, leading to a one-sided understanding of core concepts such as quick-return characteristics, dead points, and motion interference. The dynamic motion laws are reduced to static geometric relationships, which fundamentally limits the accurate transmission of mechanism theory knowledge[1].

2. The Teaching Logic Restructuring of Mechanical Engineering Courses Based on Cognitive Constructivism

2.1 The Modular Progression and Reverse Reasoning Channel in the Mechanical Principles Course

2.1.1 The Reverse Analytical Path for the Output Motion Requirements of Mechanisms

This approach takes the required displacement, velocity, or acceleration patterns of the end-effector at the output side as the starting point for analysis and then reversely determines the motion parameters of the driving link and the geometric dimensions of the components. In the teaching of planar linkage mechanisms, the teacher sets the angular displacement curve of the output link or the trajectory shape of a certain point and requires the students to reversely derive the link lengths and the positions of the hinge points. This approach introduces the content of dimensional synthesis in advance by means of the reverse solving using vector equations and the complex vector method. After the students obtain the mechanism parameters that satisfy the output requirements, they proceed to forward kinematic analysis, and the alternation of reverse and forward reasoning strengthens their understanding of the causal chain throughout the entire process of mechanism design.

2.1.2 The Reverse Transfer Rules for Component Parameters and Geometric Constraints

Each submodule in the modular structure is equipped with reverse transfer rules: when the motion indicators at the output end are not satisfied, the module sequentially transmits adjustment instructions to the upstream components until it traces back to the source of geometric constraints. In a cam mechanism, if rigid impact occurs during the return stroke of the follower, the reverse transfer path points to the adjustment nodes for the base circle radius and the eccentricity. The student needs to determine the direction for increasing the radius and recheck the pressure angle. This mechanism makes the coupling relationships among design variables explicit, thus avoiding fragmented cognition.

2.1.3 The Cumulative Verification of Inter-Module Reasoning Conclusions and Cognitive Anchoring

The verifiable intermediate conclusions obtained from the reverse reasoning step become the cognitive anchor points for entering the next module. In the study of gear mechanisms, students first reversely determine the combination of the module and the number of teeth to satisfy the gear ratio, then calculate the geometric dimensions and the contact ratio, and finally verify the tooth root bending strength and the tooth surface contact strength. The calculation conclusions of each module serve as the input conditions for the subsequent module, thus forming a cumulative verification chain. If the subsequent module fails to meet the requirements, the students trace back to the previous module and reapply the reasoning. Through the operation of "reasoning-verification-rollback," the students construct a networked cognitive structure.

2.2 The Spatial Mapping and Process Visualization Reconstruction of Manufacturing Process Knowledge Points

2.2.1 The Establishment of the Mapping Relationship Among the Workpiece, Tool, and Machine Tool Coordinate Systems

Students establish the homogeneous coordinate transformation matrix among the workpiece coordinate system (fixed to the surface to be machined), the tool coordinate system (with its origin at the tool tip point), and the machine tool coordinate system (referenced to the machine tool origin). Students need to transform the cutting edge trajectory equation of the tool from the tool coordinate system to the workpiece coordinate system, and then transform the machined surface equation to the machine tool coordinate system to obtain the feed commands for each axis. For example, when machining an inclined cylindrical hole, students transform the direction of the hole axis into the motion components of the machine tool axes through the workpiece rotation angle and the spindle tilt angle. By repeatedly performing such coordinate transformations, students gradually internalize the mathematical representation of spatial relationships within the manufacturing system.

2.2.2 The Frame-by-Frame Visualization Expression of the Cutting Trajectory and Chip Formation Process

This approach decomposes the trajectory of the tool relative to the workpiece in the cutting process into discrete time steps, with each time step corresponding to a spatial position and orientation as well as a depth of cut value. The approach adopts a motion simulation level of frame-by-frame presentation, sequentially displaying the complete process of the tool from engaging into to exiting from the workpiece. In the turning of an external cylindrical surface, students can observe the dynamic changes of the cutting thickness and the cutting width with the change of the position and orientation. In the chip formation stage, the approach uses consecutive frames to show the changes in the material flow direction in the shear slip zone and the friction area on the rake face. This expression precisely aligns the generation time points of instantaneous cutting force and cutting heat with the spatial position of the tool, thereby achieving a temporal binding of cutting parameter values with physical phenomena.

2.2.3 The Dynamic Embedding and Synchronization Relationship of Process Parameters in the Time Series

The process parameters (cutting speed, feed rate, and depth of cut) appear as fixed assignments in traditional teaching, but the process visualization reconstruction represents them as time-varying function curves and displays them synchronously with the tool motion trajectory. When milling a groove feature, the time-varying curves of the cutting thickness differ between down milling and up milling: the thickness decreases from a maximum value to zero in down milling, whereas it increases from zero to a maximum value in up milling. In the visualization interface, students simultaneously observe the dynamic evolution of the tool rotation direction, the workpiece feed direction, and the instantaneous cutting thickness curve, thus directly perceiving the influence of parameter changes on the cutting force waveform. The synchronization relationship also extends to the timing of intervention points for cooling and lubrication conditions, such as starting the coolant at the moment of tool entry and shutting it off before tool exit, in order to simulate the actual machining rhythm.

2.3 The Constraint Prioritization and Decision Node Activation in Mechanical Design Courses

2.3.1 The Matrix Representation of Assembly Constraints at the Whole-Machine Level and Strength Constraints at the Component Level

This approach establishes a constraint matrix, where the row vectors represent the levels of the mechanical system (whole machine, components, and parts), and the column vectors represent the constraint types (spatial geometric constraints, assembly sequence constraints, static strength constraints, fatigue strength constraints, and stiffness constraints). Each matrix element indicates the activation status and coupling relationship of the constraint at that level. In the design of a two-stage cylindrical gear reducer, the spatial constraint at the whole-machine level is reflected in the center distance limitation, the assembly constraint at the component level is reflected in the coaxiality requirement of the bearing housing bore, and the strength constraints at the part level are reflected in the requirement that the tooth root bending stress and the tooth surface contact stress do not exceed their permissible values. A change in the gear module simultaneously affects the center distance at the whole-machine level, the inter-shaft distance at the component level, and the tooth root stress at the part level. By consulting the matrix, students can identify all potentially restricted positions before adjusting the parameters.

2.3.2 The Trigger Thresholds and Rollback Mechanism of Design Variables at Key Decision Nodes

This approach sets up several decision nodes in the mechanical design process, with each node corresponding to the determination of the value of a design variable, and the trigger thresholds are determined by the upper or lower limits of the constraint conditions. Taking the shaft system design as an example, the first node is the estimation of the minimum diameter of the shaft (based on the torsional strength condition), with the trigger threshold being the permissible torsional shear stress. If the combination of material and diameter causes the calculated shear stress to exceed the limit, the node outputs a "fail" signal and rolls back to the material selection node. The second node is the fatigue strength check at the shaft shoulder, with the trigger threshold being the safety factor limit. When the combination of the fillet radius and the surface roughness makes the safety factor fall below the lower limit, the process rolls back to reselection. Students must pass each node before proceeding to the next node, and this mechanism enables the early exposure of design errors[2].

2.3.3 The Iterative Convergence Strategy for Design Solutions Under Multiple Coupled Constraints

When multiple constraints are triggered simultaneously, the design solution faces a nonlinear problem with multiple variables and multiple constraints. The iterative convergence strategy requires students to adjust the design variables sequentially according to the priority order of the constraints, changing only one parameter set at a time, and then recheck the solution before addressing the next constraint. In the design of a screw drive, the wear resistance constraint limits the product of the nut height and the pitch diameter of the thread, the self-locking condition constraint limits the relationship between the lead angle and the equivalent friction angle, and the screw strength constraint limits the squared relationship between the screw diameter and the load. Students first determine a preliminary combination of the pitch diameter and the nut height based on the wear resistance constraint, then check the self-locking condition. If the self-locking condition is not satisfied, the students increase the lead or reduce the number of thread starts and then return to the wear resistance check. After several rounds of alternating optimization, the design parameters gradually converge into a feasible region that satisfies all constraints, thus training the students' system-level decision-making ability under multiple coupled constraints.

3. The Dynamic Adjustment Mechanism for the Classroom Teaching Mode of the Mechanical Engineering Major

3.1 The Hierarchical Matching Strategy between Teaching Content Organization and Cognitive Rhythm

3.1.1 The Quantitative Grading of Cognitive Load for the Difficulty Gradient of Mechanical Concepts

This strategy classifies the core concepts of the mechanical engineering major into three levels according to the depth of cognitive processing. The first level consists of factual concepts, whose cognitive load is reflected in memory and recognition. The second level consists of relational concepts, whose cognitive load is reflected in the establishment of mapping relationships between variables. The third level consists of system concepts, whose cognitive load is reflected in multi-factor comprehensive reasoning. This strategy assigns quantitative load values to the multiple concepts involved in each class session to form a cognitive load curve. It arranges high-load concepts in the attention peak interval from 15 to 25 minutes after the start of the class, and arranges low-load concepts at the beginning and end of the class session.

3.1.2 The Alignment Method between Teaching Time Allocation and the Attention Fluctuation Curve

This method uses indicators such as student response time, gaze fixation duration, and exercise accuracy rates to construct individual and group attention fluctuation curves, which present three stages: an initial rising period, a peak plateau period, and a declining attenuation period. This method aligns four types of teaching activities—lecturing, demonstration, questioning, and practice—with the curve stages according to their required attention intensity. During the rising period, the method arranges factual concept reviews and simple calculations. During the peak plateau period, the method arranges high-load content such as mechanism motion analysis and mechanical response derivation. During the attenuation period, the method switches to summary chart displays or reviews of established conclusions. This alignment keeps the cognitive demand curve of teaching activities consistent with the trend of the students' available cognitive resource curve.

3.1.3 The Rhythm Control Mechanism for the Alternation between Theoretical Instruction and Exercise Intervention

The alternating rhythm between theoretical instruction and exercise intervention directly affects the effectiveness of knowledge consolidation. The rhythm control mechanism sets a standard duration threshold for each "instruction-intervention" unit. For a formula derivation that contains several sub-steps, this mechanism takes the completion of one complete sub-step as the basic instruction unit and then immediately intervenes with a micro-exercise. The feedback from the exercise determines whether to proceed to the next sub-step: if the correct rate falls below the threshold, the mechanism extends the instruction time for the current sub-step and adds alternative exercises; if the correct rate exceeds the threshold, the mechanism shortens the intervention waiting time and advances to the next step. This regulation enables the rhythm of instruction and practice to adjust adaptively based on the real-time level of mastery.

3.2 The Real-Time Intervention Method for the Analysis of Mechanism Motion and Mechanical Response in the Classroom

3.2.1 The Immediate Identification and Corrective Prompt for Abnormal Fluctuations of Kinematic Parameters

In the teaching of the instantaneous center of velocity method for planar linkage mechanisms, students tend to mark the direction of the relative instantaneous center incorrectly. The real-time intervention method pre-constructs a rule base for determining instantaneous center distributions for typical mechanisms. When a student submits the coordinates of an instantaneous center or the direction of a relative velocity, the method performs a vector comparison between the submission and the correct determination in the rule base. If an abnormal direction is detected, the system outputs a non-directive corrective prompt (such as "the instantaneous center should be located at the intersection of the perpendicular lines to the absolute velocity directions of the two links"), which triggers the student to re-examine the construction process. In the drawing of acceleration polygons, the method checks abnormal fluctuations in the direction of each acceleration component by verifying whether the normal acceleration points toward the center of curvature, and it intervenes in a timely manner to prompt the student to check the existence condition and direction determination rule of the Coriolis acceleration[3].

3.2.2 The Dynamic Deductive Intervention for Calculating Constraint Reaction Forces in the Force Transmission Path

In the force analysis of mechanical systems, the calculation of constraint reaction forces at hinges requires the correct separation of components and the application of equilibrium equations. The dynamic deductive intervention method decomposes the force analysis process into several intermediate steps, with the calculation result of each step serving as the input condition for the next step. Taking the crank-rocker mechanism as an example, this method sequentially determines the attributes of two-force members, reversely calculates the force on the connecting rod from the load on the rocker, and then transmits the force to the crank to solve for the driving torque. When the calculation result of a certain step does not satisfy the force balance relationship, the dynamic deductive intervention displays the preceding results on which this step depends and automatically replays the complete derivation chain from the initial conditions to the current step, thereby enabling students to locate the deviation node themselves through the backtracking chain.

3.2.3 The Interactive Demonstration of the Dead Point Position of a Mechanism and Motion Uncertainty

The teaching difficulty of the dead point position of a mechanism lies in the lack of intuitive perception of motion uncertainty. The real-time intervention method adopts an interactive demonstration: it introduces an adjustable linkage mechanism model, and the student drives the mechanism motion by inputting the crank angle or the lengths of the components. When the mechanism approaches the dead point, the demonstration system plots the angular velocity curve of the output link in real time and shows that the angular velocity approaches zero. After the mechanism reaches the dead point, the student attempts to drive the driving link but cannot pass it, and the system then switches to an operable interface, allowing the student to manually apply a small perturbation or adjust the inertial load to observe the conditions for passing the dead point. Through this method, the student directly establishes an empirical connection between the motion uncertainty at the dead point position and the measures for overcoming it (such as adding a flywheel or arranging multiple sets of mechanisms with staggered phases).

3.3 The Adaptive Path Generation for Mechanical Engineering Courses Based on a Disciplinary Knowledge Graph

3.3.1 The Topological Structure Modeling of the Knowledge Point Association Network for the Mechanical Engineering Discipline

This approach constructs a knowledge point network for the four core courses of mechanical principles, mechanical design, manufacturing processes, and engineering graphics. Each node in the network contains the cognitive load level, the typical class hours, and the set of prerequisite nodes. The prerequisite nodes define the other knowledge points that must be mastered before learning the given knowledge point. For example, the prerequisite nodes for the "meshing characteristics of the involute tooth profile" include the "involute equation of a circle," the "fundamental law of tooth profile meshing," and the "concept of conjugate tooth profiles." The edges in the network are assigned weights that represent the strength of dependency, which are determined by expert evaluation or the historical co-occurrence frequency. The topological structure also includes equivalent alternative paths. For instance, the "selection of the gear modification coefficient" can be accessed either through the path of "the minimum modification coefficient to avoid undercutting" or through the path of "the requirement for center distance adjustment."

3.3.2 The Detection of Students' Cognitive Status and the Recommendation of Learning Path Branches

This approach uses embedded micro-tests, concept map fill-in-the-blank questions, or short-answer questions to detect the students' mastery level of a knowledge point (not mastered, partially mastered, or fully mastered), with a focus on examining whether the students can apply the prerequisite knowledge points to subsequent problem-solving. When the detection shows that a student is in the "not mastered" status for a key prerequisite knowledge point, the adaptive algorithm determines the branching scheme based on the degree centrality of that node in the knowledge graph. For a node with a high in-degree (i.e., a node that is depended on by many subsequent nodes), the algorithm recommends a backtracking path, which goes through the direct prerequisite nodes and the sibling nodes before returning to the main path. For a node with a low in-degree and an isolated characteristic, the algorithm recommends directly relearning the node before proceeding. The student's learning path is jointly determined by the individual cognitive status and the structure of the knowledge graph.

3.3.3 The Dynamic Reorganization of the Teaching Content Sequence Driven by the Knowledge Graph

The adaptive generation of the course path is reflected in the dynamic reorganization of the teaching content sequence for each class session. Before the class, the system determines the optimal starting node and the progression order for the session based on the class's overall distribution of prerequisite knowledge mastery. When teaching "life calculation of rolling bearings," the knowledge graph shows that this node depends on "equivalent dynamic load calculation" and "basic rated life formula." If the class has good mastery of the "equivalent dynamic load calculation" link but has a weakness in the "bearing force analysis" link, the dynamic reorganization adjusts the sequence as follows: a quick review of bearing force analysis, followed by the equivalent dynamic load calculation, and then the derivation of the life formula. The reorganization also allows skipping knowledge points that are fully mastered by all students, and it allocates the saved class hours to high-difficulty coupling nodes, thereby generating the sequence based on the actual cognitive status.

Conclusion

Focusing on the reform of the classroom teaching mode for the mechanical engineering major, this study starts from the dilemmas of cognitive load and knowledge transmission and proposes a teaching logic restructuring scheme based on cognitive constructivism. This scheme includes the reverse reasoning channel for the mechanical principles course, the spatial mapping and visualization reconstruction for the manufacturing process course, and the constraint prioritization and decision node activation for mechanical design courses. Furthermore, this study establishes dynamic adjustment mechanisms, including a hierarchical teaching organization that matches cognitive load with the attention curve, real-time intervention methods, and adaptive path generation driven by a knowledge graph. Future research directions include integrating the dynamic adjustment mechanisms with intelligent teaching systems, calibrating the cognitive load model using learning behavior data, exploring the adaptability of this mode to courses such as CNC technology and robot mechanism theory, and developing lightweight tools that support real-time classroom intervention.

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