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

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Abstract: *The two problems of cognitive overload and distortion in the transmission of knowledge are facing classroom teaching of mechanical engineering. The problems are that there is no spatial map consistency between engineering graphics and manufacturing, linear structures restrict the development of systematic thinking, and there is a lack of representation for understanding dynamic mechanisms. According to the theory of cognitive constructivism, the teaching logic of this paper is organised as follows: add modules of modular reverse reasoning to the mechanical principles course, apply spatial mapping and process visualization reconstruction to the manufacturing process course, and use constraint prioritization and decision node activation in the mechanical design course. Dynamically adjust the measurement and grading of cognitive load, and regulate the rhythm of attention according to the suggestions in this paper. Another way to construct the path generation method is to use the disciplinary knowledge graph to provide an executable cognitive path for revising the teaching model.*

Keywords: *Mechanical Engineering Major; Classroom Teaching Mode; Cognitive Constructivism; Reverse Reasoning; Knowledge Graph; Dynamic Regulation*

Introduction

The Mechanical Engineering course has many kinds of various data, such as spatial geometry, kinematics, process parameters, etc. Current linear lectures and static diagrams are not very good at helping students form an all-around cognitive system of function, structure and behaviour. Engineering graphics and production processes are done together, and the cognitive switching cost is relatively high. Loss of the time dimension in the results of dynamic analysis results in a one-sided view of concepts such as dead points. The Design Constraints are mentioned in all the chapters and are not introduced early on. The above contradictions indicate that the traditional way of teaching mechanical engineering does not comply with the laws of cognition. Therefore, we need to change the teaching logic in line with the ideas of cognitive constructivism and add dynamic adjustment devices. Therefore, based on the laws of cognition, research on the reform of teaching modes is urgently needed at present.

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 two main directions of the engineering graphics course are the conversion of a 3D object into a 2D drawing and the reconstruction of a 3D object from a 2D drawing. All of the above need to use visuospatial working memory. There are many links in the course of production, such as cutting motion, tool shape, fixture position and process order. Students should be able to imagine the process of material removal and the working of a machine tool. If the two courses are taught together in the same semester or consecutively, students' cognitive systems will have to switch frequently between the graphic symbol system and the process entity system. The switch will take away some of the child's energy and cause them distress. For example, students may confuse the direction of unfolding of a projection plane with the feed direction of a process and form a conceptual fixation that is difficult to correct.

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

The current classroom teaching of the mechanical engineering major generally follows the order of chapters and is a linear progression of part design, mechanism motion, transmission system and manufacturing process. It is a list of knowledge points in order, not a graph. When students are learning the calculation of gear parameters, they find it difficult to apply this knowledge to the gear processing methods and inspection standards mentioned later in the text. When they learn the Design of shafting components, they do not know in advance about the assembly sequence and manufacturability. The Structure of the linear lacks some function links. Although students can perform calculations or remember some individual pieces of knowledge, they are unable to build a whole-machine-level functional transmission chain and constraint propagation path in their minds; thus, they have not developed mechanical system thinking.

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

In a traditional lecture, the kinematics of a mechanism is shown in simple two-dimensional diagrams on a static board, slides, textbooks, etc. For the variation patterns of the displacement, velocity and acceleration of the follower with the cam angle in a cam mechanism, and also for the continuous generation process of the coupler curve in a four-bar linkage, static diagrams can only show a few discrete positions and orientations. Even if the teacher adds verbal descriptions to the diagrams, it is still difficult for students to understand the change in motion and instantaneous velocity at different positions and orientations. Such a type of representation does not have continuous information in the time dimension and therefore cannot show all the main features of quick return, dead points and motion interference. The laws of motion for dynamics have been reduced to static geometric relations, so the theory of mechanisms cannot be applied accurately[1].

2. 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

The required patterns of displacement, velocity and acceleration for the end-effector at the output side are taken as the starting point for analysis, and then the motion parameters of the driving link and the geometric dimensions of the components are determined in reverse. In the teaching of planar linkage mechanisms, the teacher can set the angular displacement curve of the output link or the shape of the trajectory for a particular point and have the students work backward to find the link lengths and positions of the hinge points. In preparation for the above, the content of dimensional synthesis can be obtained by means of reverse-solving for vector equations and the complex vector method. After the students have obtained the mechanism parameters that meet the output requirements, they will perform a forward kinematic analysis, and by alternating between reverse and forward reasoning, they can better grasp the cause-and-effect chain of mechanism design in this process.

2.1.2 Reverse Transfer Rules for Component Parameters and Geometric Constraints

Each submodule in the modular structure has its own inverse transfer rule, and if the motion indicators at the output end are not realised, this module will sequentially pass adjustment instructions to the upstream components and trace back to the source of the geometric constraint. If there is a sudden shock in the return stroke of the follower of a cam mechanism, the reverse transfer path will cause changes in the nodes for the base circle radius and eccentricity. The student should decide how much to increase the radius and then re-verify the pressure angle. Therefore, one can show the interdependence of the Design Variables more clearly and avoid fragmentation.

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

The verifiable intermediate results of the reverse reasoning step provide the basis for the next module. In the study of gear mechanisms, students first determine the combination of the module and the number of teeth inversely according to the desired 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 results of each module are taken as the input for the next module, so there is a chain of cumulative verification. If the next module does not meet the requirements, the students will go back to the previous module and reapply the reasoning. The three operations of "reasoning-verification-rollback" are used to construct a network of knowledge.

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

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

Students need to construct the homogeneous coordinate transformation matrices for the workpiece coordinate system (fixed on the surface of the machined part), the tool coordinate system (origin at the tip of the tool), and the machine tool coordinate system (referenced to the machine tool origin). Students need to change 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 instance, to machine an inclined cylindrical hole, one can use the workpiece rotation angle and spindle tilt angle to convert the direction of the hole axis into motion components for the machine tool axes. A few coordinate transformations can be used to learn how to express the location of objects on the production line in coordinates.

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

The path of the tool relative to the workpiece in the cutting process is divided into a number of small steps, and each step has an associated position and direction, as well as a depth of cut value. Therefore, we will show the entire process of the tool, from contact with the workpiece to separation, in motion simulation, frame by frame. When rolling the outside of a cylinder, students can observe that the thickness and width of the cut vary according to the position and direction of the cut. At the stage of chip formation, consecutive frames are used to show the change in the direction of material flow in the shear slip zone and the friction area on the rake face. The above form shows that the generation time of the instantaneous cutting force and cutting heat is in line with the position of the tool; thus, the cutting parameter values can be correlated with real-world physical phenomena over time.

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

Traditionally, the teaching method sets the values of the process parameters (cutting speed, feed rate and depth of cut), but process visualisation reconstruction shows that these are actually time-varying function curves and displays them along with the tool motion path. Milling a groove feature, the time-varying curve of the cutting thickness is different for down milling and up milling; in down milling, the thickness decreases from a maximum value to zero, and in up milling, it increases from zero to a maximum value. In the visualisation window, it can be seen how the direction of tool rotation, workpiece feed and instantaneous cutting thickness curve change together, and thus the effect of modifying parameters on the cutting force waveform can be understood. Synchronization also refers to the time of the intervention point for cooling and lubrication conditions; for instance, one can start the coolant at the time of tool entry and stop it before tool exit to simulate the actual machining rhythm.

2.3 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

The way to build a constraint matrix is to put the levels of the mechanical system in rows (whole machine, components and parts), and the types of constraints are in columns (spatial geometric constraints, assembly sequence constraints, static strength constraints, fatigue strength constraints and stiffness constraints). Each element of the matrix is the activation state and coupling 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 shown by the limit on the center distance; the assembly constraint at the component level is the requirement for coaxiality of the bearing housing bore; and the strength constraint at the part level is that the tooth root bending stress and the tooth surface contact stress should not exceed their respective allowable values. Modifying the gear module will change the centre distance of the entire machine, alter the inter-shaft distance at the component level, and thus affect the tooth root stress of that part. All the possible restricted positions can be found in the matrix before changing the parameters.

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

Therefore, there will be several decision points in the mechanical Design process, and at each point, we will determine the value of a Design parameter based on whether it exceeds the upper or lower limits of the constraint conditions. The first step in the Design of the shaft system is to determine the minimum diameter of the shaft according to the condition of torsional strength, and the trigger threshold is the allowable torsional shear stress. If the sum of the material and diameter exceeds the upper limit for shear stress, then the node will output a "fail" signal and return to the material selection node. The second node is the fatigue strength check at the shaft shoulder, and the trigger threshold is the safety factor limit. If the combination of fillet radius and surface roughness is lower than the minimum for the safety factor, repeat the above process to select another one. The student needs to pass the current node to move to the next one; otherwise, they will not be allowed to proceed[2].

2.3.3 Iterative Convergence Strategy for Design Solutions under Multiple Coupled Constraints

When there are many constraints at the same time, the Design Problem is non-linear and has many variables and constraints. Iterative convergence method: Adjust the design parameters one by one according to the priority of the constraints, change only one set of parameters at a time, and then re-evaluate the solution before moving on to 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. According to the demands of wear resistance, the student first chooses a starting pair of pitch diameter and nut height, and then verifies that it is self-locking. If the self-locking condition is not met, the students will increase the lead or decrease the number of thread starts, and then return to the wear resistance check. After several rounds of alternating optimisation, the Design Parameters have gradually converged to an area that meets all the requirements, and then training will be carried out on the students' system-level decision-making ability under various coupled constraints.

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

3.1 The Hierarchical Matching Strategy for Teaching Content Organisation and Cognitive Rhythm

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

The three grades of division for the main ideas in the mechanical engineering major are based on different levels of cognitive processing. The first level is factual knowledge; it has a small cognitive load and can be recalled. The second level is relational concepts, and at this time, the cognitive load is shown in the construction of mappings among variables. The third level is system concepts, and the cognitive load of these can be judged by the following indicators. Distribute the weight of all the concepts in a single class among them to form a cognitive load curve. High-load concepts are placed in the attention peak window of 15-25 minutes after the start of class, and low-load concepts are placed at the beginning and end of the class period.

3.1.2 Alignment Method for Teaching Time Allocation and Attention Fluctuation Curve

The index of attention fluctuation is the response time, the duration of gaze fixation and the accuracy rate in exercises by students; they are used to construct individual and group attention fluctuation curves, which generally have three stages: an initial rise, a peak plateau and a decline. The four types of teaching activities correspond to the stages of the curve and require different levels of concentration. At the beginning, there will be some introductions to the subject and basic knowledge. At the top plateau, one can set up a problem of a high load and then derive the mechanical response. There will be summaries and analyses of the results obtained so far in the attenuation period. Therefore, the organisation of teaching activities will be in line with the development of students' cognitive abilities at present.

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

Alternate between teaching theory and having students practise; in this way, they will remember what they have learned better. Set the length of each "instruction-intervention" period in the Rhythm

Control Mechanism. For derivation of a formula with many sub-steps, one should take the completion of one full sub-step as the basic instruction unit and immediately present a micro-exercise. Based on the feedback from the exercise, it will be decided whether to proceed to the next sub-step; if the correct rate is below the threshold, the mechanism will extend the instruction time of the current sub-step and add more exercises; if it exceeds the threshold, the intervention waiting time will be reduced and the next step will be started. According to how well the students learn in class, we will adjust the speed of teaching and training.

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

3.2.1 Prompt Identification and Correction of Abnormal Fluctuations in Kinematic Parameters

In teaching the method of the instantaneous centre of velocity for planar linkage mechanisms, students often mark the direction of the relative instantaneous centre incorrectly. The first two lines are the rule base and the immediate centre distribution of a typical mechanism, respectively. When a student enters the coordinates of an instantaneous centre or the direction of a relative velocity in the system, it will be compared with the correct values in the rule base. If the direction is incorrect, the system will show a non-directive correction prompt (e.g., "the instantaneous center should be at the intersection of the perpendicular lines to the absolute velocity directions of the two links"), and the student will need to redo the construction. In the drawing of acceleration polygons, one should check for any abnormal fluctuations in the direction of each component of acceleration by verifying whether the normal acceleration points towards the center of curvature, and promptly guide the student to investigate the necessary conditions for the existence and direction determination rules of Coriolis acceleration[3].

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

To find the reaction forces at the hinges in the force analysis of a mechanical system, it is necessary to divide the system properly and use the equilibrium equations. There are several steps in the process of force analysis for the dynamic deductive intervention method, and the calculation results at each step are taken as the input conditions for the next step. As shown in the example of a crank-rocker mechanism, the properties of the two-force member are determined first, then the force at the connecting rod can be calculated inversely based on the load at the rocker, and finally, this force is transmitted to the crank to find the driving torque. If the calculation result of a particular step does not meet the force balance condition, the dynamic deductive intervention will display the previous results on which this step is based and automatically retrace the entire derivation process from the initial conditions to the current step, allowing students to find the deviation node themselves by following the backtracking chain.

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

The teaching difficulty of the dead-point position for a mechanism is that it is not easy to feel the motion uncertainty intuitively. The other kind of live teaching is interactive demonstration; a model of an adjustable-linkage mechanism will be employed, and students can change the motion of the mechanism by varying the crank angle or the lengths of the components. It is about to reach the dead zone, so the demonstration system will obtain the angular velocity curve of the output link in real time and show that the angular velocity is close to zero. When the mechanism reaches the dead point, the student attempts to move the driving link but cannot do so; at this time, the system will switch to operating mode and allow the student to apply a small manual disturbance or change the inertial load to see if it can pass the dead point. Therefore, the student will have obtained direct empirical evidence of the motion uncertainty at the dead-point position, and based on this, can add a flywheel or arrange several sets of mechanisms with staggered phases.

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

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

The four basic courses of mechanical principles, mechanical design, manufacturing processes and engineering graphics constitute the foundation of the knowledge point network. Every node in the network has a cognitive load, a typical number of class hours, and a set of prerequisite nodes. The prerequisite nodes are the other knowledge points that need to be learned before learning the current knowledge point. For example, the prerequisite nodes of "meshing characteristics of the involute tooth profile" are "involute equation of a circle", "fundamental law of tooth profile meshing" and "concept of conjugate tooth profiles". Edges in the network are given weights to show the degree of dependence, and these weights can be set by experts or based on how often they have occurred in the past. There are other kinds of Topologies as well. For example, to find the "selection of the gear modification coefficient", one can take the path of "the minimum modification coefficient to avoid undercutting" or follow the path of "the requirement for centre distance adjustment".

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

Therefore, add micro-tests, concept map fill-in-the-blank questions or short-answer questions to determine how well students have learned a particular part of the knowledge (not mastered, partially mastered, or fully mastered), and pay attention to whether they can apply the prerequisite knowledge points in the next problem. If the detection finds that a student has not mastered a required point of prerequisite knowledge, then according to how central that node is in the knowledge graph, a branch plan will be used. For a node with a large in-degree (that is to say, a node that needs to be referenced by many subsequent nodes), the algorithm proposes backtracking; this path will go through the immediate prerequisite nodes and sibling nodes before returning to the main path. A node with a small in-degree and an isolated state will be directly learned by the algorithm, and then it will be skipped. The student's learning path is determined by both their own cognitive conditions and the structure of the knowledge graph.

3.3.3 Dynamic Rearrangement of the Teaching Content Sequence Driven by the Knowledge Graph

Adaptive generation of the course path is achieved by modifying the order of teaching content in each class. Based on the whole distribution of prerequisite knowledge mastery in the class before the class, the system will select an optimal starting node and progression order for the session. In teaching "Life calculation of rolling bearings", the knowledge graph shows that this node is dependent on "Equivalent dynamic load calculation" and "Basic rated life formula". If the class has a good understanding of the "equivalent dynamic load calculation" link but is weak in the "bearing force analysis" link, dynamic reorganization will adjust the order as follows: a quick review of bearing force analysis, followed by the equivalent dynamic load calculation, and then the derivation of the life formula. Reorganisation can also skip knowledge points that have been fully mastered by all students, and the saved class time can be used to create a sequence based on the actual cognitive status of high-difficulty coupling nodes.

Conclusion

The first part of this paper is to present the problems of cognitive load and knowledge transmission in the reform of classroom teaching mode for the mechanical engineering major, and then, based on cognitive constructivism, propose a teaching logic restructuring plan. The three are: the reverse reasoning channel for the mechanical principles course, the spatial mapping and visualisation reconstruction for the manufacturing process course, and the constraint prioritisation and decision node activation for mechanical design courses. Some other adaptation measures mentioned in this paper are a hierarchical teaching organisation that matches cognitive load with the attention curve, real-time intervention methods, and adaptive path generation based on a knowledge graph. In the future, we will research how to add dynamic adjustment mechanisms to intelligent teaching systems, modify the cognitive load model based on data of students' learning behaviour, study the application of this mode in courses such as CNC technology and robot mechanism theory, and develop lightweight tools for real-time intervention in the classroom.

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