Analysis of the Application Effect of Project-Based Teaching Method in the Machining Process Course

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Abstract: *The hierarchical progressive knowledge system and implicit skill composition of the Machining Process Course require a situation-driven mechanism for the teaching method. The Project-Based Teaching Method establishes a dynamic coupling between task situations and cognitive structures through a five-stage nonlinear path, forming a many-to-many mapping with the process capability objectives. This method drives the structured reorganization of knowledge points along the processing flow, strengthens the logic of multi-attribute decision-making, and prompts learners to develop parameter correction strategies through cognitive conflict. Regarding the application effects, this paper proposes a quantitative characterization system that includes knowledge retention rate, transfer efficiency, error tracing, and stability judgment criteria, and divides the optimization magnitude into three innovation levels: the parameter level, the process level, and the principle level.*

Keywords: *Machining Process Course; Project-Based Teaching Method; Structured Reorganization of Knowledge; Strengthening of Decision-Making Logic; Cognitive Conflict; Application Effect Evaluation*

Introduction

In the Machining Process Course, learners need to progress step by step from factual memory to strategic evaluation. However, traditional teaching methods can hardly convey implicit process knowledge effectively. Moreover, the generation of process plans involves multi-attribute decision-making, and learners often find it difficult to internalize the prioritization logic of constraints due to a lack of situation-driven mechanisms. The Project-Based Teaching Method stimulates cognitive imbalance by embedding process contradictions into task situations, prompting learners to reconstruct the weights of process rules through scheme demonstration and iteration. This process plays an irreplaceable role in improving the retention rate of process knowledge, the transfer efficiency, and the ability to trace errors. Nevertheless, existing research mostly focuses on the design of teaching procedures, lacking a systematic analysis of the mapping relationship between the Project-Based Teaching Method and the ability training objectives of the process course. Nor has it established a quantitative evaluation system for the precision stability of process implementation and the innovation level of optimization behaviors. Therefore, it is necessary to analyze the application effect of this method from three levels (theoretical foundation, mechanism of action, and characterization indicators) so as to provide an operable evaluation framework for the teaching reform of the process course.

1. Theoretical Basis and Applicability Analysis of Integrating the Project-Based Teaching Method into the Machining Process Course

1.1 Knowledge Hierarchy and Skill Composition Characteristics of the Machining Process Course

The knowledge system of the Machining Process Course presents a significant hierarchical progressive structure. The bottom layer consists of basic concepts such as materials science, cutting principles, and machine tool kinematics. The middle layer includes process planning rules such as procedure design, datum selection, and positioning and clamping schemes. The top layer involves comprehensive decision-making logics such as the construction of machining accuracy chains, the stiffness matching of process systems, and the optimization of cutting parameters. Strict causal dependencies exist among the knowledge at different layers. For example, the selection of cutting parameters needs to be based on the quantitative relationship between the heat resistance of tool materials and the hardness parameters of the workpiece. This characteristic determines that learners must experience a step-by-step progression from factual memory to rule application and then to strategic evaluation in their cognitive process[1].

The skill composition of this course centers on the analytical ability of the process system, which includes the tolerance decomposition skill in drawing interpretation, the temporal logic skill in process route planning, and the abductive reasoning skill in machining error diagnosis. These skills do not exist in isolation; instead, they achieve synergy through the carrier of process document preparation. Each skill element corresponds to observable behavioral indicators; for example, the degree of application of the datum coincidence principle can be judged by the accuracy of positioning symbol marking in the process sketch. The characteristics of skill composition are also reflected in the dependence on implicit process knowledge, such as the empirical rule for adjusting the tool overhang amount in cutting vibration control. This type of knowledge is difficult to convey through declarative teaching and needs to trigger its internalization mechanism in a problem situation.

1.2 Process Deconstruction and Interaction Principle of the Project-Based Teaching Method

The process of the Project-Based Teaching Method can be deconstructed into five continuous stages: task release, scheme generation, resource allocation, periodic feedback, and outcome iteration. Each stage contains specific cognitive operations: the task release stage requires learners to perform goal decomposition and constraint identification; the scheme generation stage involves multi-path comparison and feasibility screening; and the resource allocation stage requires the completion of matching calculations between equipment capacity and machining time. These stages form a closed-loop structure with feedforward and feedback connections; for example, the results of periodic feedback trigger corrective actions in the scheme generation stage, thereby constructing a nonlinear learning path.

The interaction principle of the Project-Based Teaching Method is based on the dynamic coupling between the task situation and the learner's cognitive structure. The process contradictions embedded in the task situation (such as the conflict of cutting parameters that simultaneously meet productivity and surface quality requirements) stimulate the learner's cognitive imbalance, prompting him or her to retrieve existing knowledge and attempt heterogeneous scheme combinations. The intensity of the interaction depends on the difference gradient between the task authenticity and the learner's existing experience; if the difference is too small, it fails to trigger deep processing, and if the difference is too large, it leads to cognitive overload. This principle also involves the dimension of social interaction, namely the behaviors of argumentation and evidence exchange among learners during the scheme demonstration process. These behaviors reconstruct the individual's subjective judgment of the weights of process rules, thereby affecting the decision-making preferences in subsequent tasks[2].

1.3 Mapping Relationship Between the Project-Based Teaching Method and the Ability Training Objectives of the Process Course

A many-to-many mapping structure exists between the task characteristics of the Project-Based Teaching Method and the ability training objectives of the process course. The “procedure flow design ability” in the process course corresponds to the sub-objective of “complete path planning from blank to finished product” in the project task, and the mapping medium is the preparation activity of the process documentation. The constraint conditions set in the project task (such as equipment type restrictions or process concentration requirements) directly map onto the evaluation dimensions of the “process scheme optimization ability” in the course. The establishment of the mapping relationship needs to satisfy the consistency condition, which means that the cognitive operation type required by the project task should be isomorphic with the thinking process involved in the target ability; for example, the tolerance allocation ability requires the project task to include a specific situation of dimensional chain calculation.

Further analysis shows that the evaluation mechanism in the Project-Based Teaching Method forms a feedback mapping with the ability achievement indicators in the process course. The “process parameter adjustment ability” required by the course maps onto the comparative experiment design of cutting speed and feed rate in project iterations, where learners record the machining results under different parameter combinations and then reverse-correct their initial decisions. This mapping is bidirectional; the ability deficiencies in the course (such as the neglect of the thermal deformation compensation rule) are explicitly exposed during the error analysis phase of the project task, thereby forming a diagnostic signal for learning weaknesses. The density of the mapping relationship determines the completeness of the teaching method's coverage of the course objectives; when the number of process decision-making nodes contained in the project task exceeds the number of core nodes required in the course ability list, the mapping can be considered to have reached a sufficient condition.

2. Mechanism of the Project-Based Teaching Method on the Learning Effectiveness of Machining Process

2.1 Serial Connection and Structured Reorganization of Process Knowledge Points Guided by the Project Task Chain

The project task chain drives learners to connect the knowledge points originally scattered across various chapters of the course along the processing flow by setting up progressive process problem situations. For example, in the complete chain from blank type identification to process margin allocation and then to cutting parameter determination, knowledge points such as material machinability, machine tool power constraints, and tool wear laws are forced to be invoked under the same decision-making framework. This method of serial connection breaks the linear presentation order classified by knowledge attributes and instead uses the timeline of process logic as the basis for reorganization, so that the causal relationships among knowledge points (such as the influence mechanism of feed rate variation on surface roughness) obtain explicit expression during task execution[3].

The essence of structured reorganization is the redistribution of connection strengths among knowledge nodes. In the process of completing the project task chain, learners need to identify which knowledge points belong to the solution elements of the same process sub-problem and cluster them into functional knowledge modules. For example, in a shaft part machining task, the type selection of center holes, the mechanical model of double-center positioning, and the adjustment rules of tailstock pressure are integrated into an "axial positioning module." At the same time, the invocation weight of knowledge nodes unrelated to the current task in the original course system (such as the principles of non-traditional machining) is temporarily suppressed. This modular reorganization improves the retrieval efficiency of process knowledge in problem situations and prompts learners to form a knowledge organization method based on machining features rather than the linear storage structure arranged according to textbook chapters.

2.2 Strengthening Path of Decision-Making Logic in the Process Scheme Generation Process

The generation of a process scheme involves a multi-attribute decision-making process, where learners need to make trade-offs among multiple dimensions such as accuracy grade, production efficiency, cost constraints, and equipment availability. The Project-Based Teaching Method forces learners to establish a decision-making chain from machining feature analysis to procedure sequence generation by setting clear scheme output requirements (such as preparing a complete process documentation card). Each decision node (for example, deciding whether to separate rough machining and finish machining) requires the invocation of corresponding process criteria (such as the deformation control principle), and repeating such invocation operations strengthens the conditioned reflex association between rules and situations. This strengthening manifests itself as the learner's ability to identify the boundary conditions of applicable rules more quickly in subsequent new tasks, such as judging under which tolerance grade a semi-finishing procedure must be introduced.

The strengthening path of decision-making logic is also reflected in the pruning mechanism of invalid branches. Learners often propose multiple possible positioning methods or tool paths in their initial schemes, and they gradually eliminate infeasible options through the resource constraints embedded in the project task (such as specifying the machine tool type or tool inventory). Repeatedly experiencing the process of “proposing alternative schemes, testing constraint conditions, and excluding rule-violating options” prompts learners to internalize the prioritization logic of constraints. For example, when the equipment accuracy is insufficient, the selection of the process scheme tends to prioritize reducing the number of clamping setups rather than increasing the cutting speed. This internalized decision-making logic is transferable; when facing new workpiece materials or different batch size requirements, learners can apply the same constraint prioritization framework to adjust the scheme without needing to re-establish the decision rule system[4].

2.3 Cognitive Conflict and Resolution Strategies in the Iterative Adjustment of Process Parameters

In the iterative adjustment of process parameters, the deviation between the theoretical machining result (such as the predicted surface roughness) calculated by the learner based on the initial parameters and the actual measured result constitutes the triggering condition for cognitive conflict. For example, the turning parameters selected according to the machining handbook produce unexpected vibration marks in actual machining, and this conflict stems from the mismatch between the recommended values in the handbook and the actual stiffness of the process system. The intensity of the cognitive conflict depends on the magnitude of the deviation and its impact on subsequent processes; when the deviation leads to the scrapping of the workpiece, the conflict intensity reaches its peak. At this point, the learner's degree of doubt about the original parameter selection basis is the highest, thereby generating the motivation to reconstruct the cognitive schema.

The generation of resolution strategies follows the logic of hypothesis testing. The learner first locates the source of the deviation, which may include tool wear, insufficient cutting fluid supply, or an unreasonable combination of cutting parameters, and then changes one parameter at a time for verification. For example, the learner keeps the cutting speed unchanged while reducing the feed rate and observes whether the vibration disappears, thereby determining the root cause of the problem. Through multiple iterations, the learner summarizes the parameter correction coefficients under specific working conditions (such as multiplying the recommended feed rate by a safety factor of 0.6 for slender shaft turning). This complete closed loop from conflict identification and hypothesis formulation to parameter adjustment verification not only corrects the parameter settings for the current task but also establishes a critical habit of using the recommended values in the process handbook. When a similar conflict occurs again, the path length of the learner's parameter adjustment is significantly shortened, which is manifested as directly skipping some low-probability hypotheses and focusing on the high-frequency conflict sources from past experience, such as prioritizing clamping deformation over tool wear in thin-walled part machining.

3. Evaluation System and Characterization Indicators for the Application Effect of the Project-Based Teaching Method

3.1 Quantitative Characterization Parameters for Process Knowledge Retention Rate and Transfer Efficiency

The process knowledge retention rate can be quantitatively characterized through two dimensions: the correct recognition rate and the accurate reproduction rate in delayed testing. The correct recognition rate refers to the learner's recognition accuracy of key process concepts (such as the six-point positioning principle and the machining allowance allocation rules) after a certain time interval following the completion of the project task. This measurement uses closed-ended process scenario judgment questions, with the distractors set as expressions that are of the same type but contain logical errors. The accurate reproduction rate requires the learner to write out the complete standard process route for a certain type of part (such as a rotational part) without referring to the original materials and to match it against a template at the procedure level. The matching degree is calculated jointly using the consistency coefficient of the procedure order and the error rate of parameter values. The two indicators can be weighted and combined into a comprehensive retention rate, with the weight coefficients determined according to the core degree of the knowledge point in the course objectives[5].

Transfer efficiency reflects the learner's ability to apply the acquired process knowledge to heterogeneous machining situations. Its characterization parameters include the initial decision-making delay time and the number of scheme revisions. The initial decision-making delay time refers to the time interval from the presentation of the problem to the proposal of the first feasible process scheme when facing a new part drawing, and this parameter is negatively correlated with knowledge transfer efficiency. The number of scheme revisions records the number of defects in the learner's own scheme that he or she discovers during the process review session, with each revision corresponding to one knowledge backtracking behavior. By establishing a benchmark task (such as a simple stepped shaft) and a transfer task (such as a short shaft with an eccentric part), the relative transfer efficiency can be calculated. The formula is the ratio of the number of revisions in the benchmark task to the number of revisions in the transfer task; the closer this ratio is to 1, the lower the information loss in the knowledge transfer process.

3.2 Error Tracing and Stability Judgment Criteria for Machining Implementation Accuracy

Error tracing for machining implementation accuracy is based on the deviation decomposition method between the machining result and the design requirement. The total deviation is decomposed into components such as positioning error, tool setting error, machine tool geometric error, and thermal deformation error, and each component corresponds to a traceable specific decision node in the project task. For example, the selection of the workpiece positioning surface directly affects the calculated value of the positioning error, while the degree of process concentration affects the accumulation of tool setting errors introduced by multiple clampings. By establishing a deviation transfer matrix, the contribution of each process decision node to the final accuracy indicator can be quantified. The output form of error tracing is a contribution ranking list, in which nodes whose contribution exceeds a preset threshold (such as 15%) are marked as accuracy-sensitive nodes.

The stability judgment criterion adopts the control chart method to analyze the repeated machining results. For the key dimension data (such as the outer diameter) of the same process scheme after multiple executions, the method plots the mean-range control chart and calculates the upper and lower control limits. When multiple consecutive sample points (such as 7 points) all fall on the same side of the center line, or when a point appears outside the control limits, the method determines that the process system is in an unstable state. The cause of the unstable state can be traced back to specific parameters in the process scheme, such as an excessively large fluctuation range of the cutting depth or an improperly set tool wear compensation cycle. Another judgment indicator for stability is the process capability index, which reflects the output consistency of the process scheme within the tolerance band width. When the index is below 1.33, the method considers that the inherent variability of the process scheme exceeds the design tolerance range, and the safety margin setting of the process parameters needs to be re-examined.

3.3 Innovation Level Classification and Evaluation Basis in Process Optimization Behavior

The innovation level of process optimization behavior is classified according to the combination characteristics of the optimization object and the optimization magnitude. The first-level optimization (parameter level) manifests itself as the adjustment of continuous variables in the existing process scheme, such as cutting parameters, tool geometric angles, or coolant pressure, without changing the procedure sequence and the positioning method. The optimization magnitude is measured by the shortening rate of machining time or the reduction amount of surface roughness. The second-level optimization (procedure level) involves procedure merging, procedure splitting, or procedure sequence rearrangement, for example, combining rough turning and semi-finishing into one pass, or changing the order of the heat treatment procedure and the finishing procedure. The third-level optimization (principle level) refers to the introduction of heterogeneous machining methods (such as replacing turning with grinding) or the redesign of the positioning scheme (such as converting from a single datum to over-positioning). This type of optimization changes the basic logical framework of the process scheme.

The establishment of the evaluation basis requires setting operable judgment conditions for each innovation level. For parameter-level optimization, the basis is the boundary extension amount of the parameter value range in the original scheme; when the new parameter exceeds 30% of the recommended range in the original handbook and is verified to be feasible through actual machining, it can be recognized as an effective innovation. For procedure-level optimization, the basis is the net reduction in the number of procedures or the reduction in the number of clamping setups after process concentration; a reduction exceeding one clamping setup meets the judgment condition. For principle-level optimization, the basis is whether the new machining principle adopted is not recorded in the typical process documentation for similar types of parts, which can be confirmed by comparison with a standard process database. The innovation behaviors at different levels are not mutually exclusive; a single process optimization may include both procedure-level adjustments and parameter-level adjustments. In this case, the classification follows the highest level to avoid evaluation deviations caused by duplicate counting.

Conclusion

The Project-Based Teaching Method drives the structured reorganization of knowledge points along the processing flow through a task chain, prompting learners to form functional knowledge modules based on machining features and changing the original knowledge organization method of linear storage according to textbook chapters. At the level of decision-making logic, the repeated invocation of rules in the multi-attribute decision-making process and the pruning mechanism of invalid branches strengthen the decision-making chain from machining feature analysis to procedure sequence generation. During the iterative adjustment of process parameters, the cognitive conflict triggered by the deviation between theoretical calculation and actual measurement follows the logic of hypothesis testing to generate parameter correction strategies, thereby establishing a critical habit of using the recommended values in the process handbook. Regarding the application effects of the above mechanisms, the proposed evaluation system includes four interrelated modules: the process knowledge retention rate is quantified by the weighted synthesis of the correct recognition rate and the accurate reproduction rate; the transfer efficiency is characterized by the ratio of the initial decision-making delay time to the number of scheme revisions; error tracing for machining implementation accuracy calculates the contribution of each decision node based on the deviation transfer matrix and marks nodes exceeding the threshold; stability judgment adopts the mean-range control chart and the process capability index (values below 1.33 are judged as unstable); the innovation level of process optimization behavior is divided according to the optimization object and magnitude into the parameter level (adjustment of continuous variables), the procedure level (procedure merging or sequence rearrangement), and the principle level (introduction of heterogeneous machining methods or redesign of positioning schemes), with operable judgment conditions established for each level. This evaluation system constitutes a complete analytical framework for the application effect. Future directions can further explore the differential influence of different part types (such as box-shaped parts and irregular parts) on the topological structure of the project task chain, while introducing a machine learning-based behavior pattern recognition method for process decision-making. By collecting learners' parameter selection trajectories and correction records, this approach can achieve dynamic calibration of evaluation indicators and personalized diagnostic feedback.

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