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

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Abstract: *The course of the Machining Process has a hierarchical progressive knowledge system and implicit skill composition, so a situation-based teaching method should be used. The five steps of Project-Based Teaching can form a good link between the situation of a task and cognitive structure, and they are many-to-many mapped with process capability goals. Therefore, the knowledge points will be organised systematically in the processing path, the logic of multi-attribute decision-making will be strengthened, and learners will be motivated to develop parameter correction strategies through cognitive conflict. In terms of the effect of application, this paper offers a quantitative characterisation system for the three problems of knowledge retention rate, transfer efficiency, error tracing and stability judgment criteria, and the three levels of optimisation magnitude are the parameter level, the process level and the principle level.*

Keywords: *Machining Process Course, Project-based teaching method, Structured organisation of knowledge, Strengthening of decision-making logic, Cognitive conflict, Application effect evaluation*

Introduction

Learners of the Machining Process Course should be able to apply what they have learned and make reasonable judgments about it. The old way of teaching does not reveal the hidden process knowledge easily. There are many attributes of the construction of process plans, and learners often fail to consider the priority rules of constraints because they are not well-acquainted with the particular circumstances. A problem of process contradiction will be created in the situation of the task by Project-Based Teaching, and students will reconstruct the weight of process rules through scheme presentation and repetition. The above can help to improve the retention of process knowledge and the effectiveness of its application and error tracing. However, most of the previous research has focused on the design of teaching procedures and has not systematically studied the mapping relationship between the Project-Based Teaching Method and the ability training objectives of the process course. There is no system to determine the accuracy and stability of the process execution, so no efforts will be made to strengthen it. Therefore, in order to develop an operating evaluation plan for the teaching reform in the process course, the application effect of this method at the three levels (theoretical foundation, mechanism of action and characterization indicators) needs to be studied.

1. Theoretical Foundation and Application Analysis of Integrating the Project-Based Teaching Method in 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 has a general hierarchical and progressive structure. The lower level covers the basic knowledge of materials science, cutting theory and machine tool kinematics. The rules of the middle stage are to organise the production process, establish datums and set up positioning-and-clamping schemes. At the top level are all kinds of decision logics, such as building accuracy chains for building machine machining, stiffness matching of process systems, optimisation of cutting parameters, etc. There are many causal links among the knowledge at all levels. For example, the cutting parameters should be selected according to the heat-resistance capacity of the tool material and the hardness parameters of the workpiece. Therefore, the desired qualities of students are to be able to remember facts, apply rules, and finally use them correctly[1].

The skills that will be learned in this course are how to analyse process systems, and they include the skill of tolerance decomposition in drawing interpretation, the temporal logic skill for process route planning, and the abductive reasoning skill of machining error diagnosis. The above skills are not to be used independently but combined in the preparation of process documents. All skill elements are behaviours that can be observed; for instance, the extent of the application of the datum coincidence principle can be judged by the accuracy of the positioning symbol marking in the process sketch. The characteristics of skill composition can also be observed in the use of implicit process knowledge, such as the empirical rule for adjusting the amount of tool overhang in cutting vibration control. This kind of knowledge is not easy to present in a declarative manner, so we need to activate the mechanism of internalisation by posing a problem.

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

The five steps of the teaching process in the project method are task release, scheme generation, resource allocation, periodic feedback and outcome iteration. The three periods have different modes of thought: at the time of task release, students need to set goals and consider constraints; in the stage of scheme generation, they must consider many options and check for feasibility; and during resource allocation, they need to match the capacity of equipment with machining time. The above stages form a closed-loop system with feedforward and feedback connections; for instance, the results of periodic feedback can cause changes in the scheme generation stage and thus form a nonlinear learning path.

The rule of interaction in Project-Based Teaching is to change the circumstances of a task according to changes in students' cognitive development. There is a conflict in the conditions of the task (e.g., high productivity and a good surface finish both need to be achieved, but they require different cutting parameters), which causes a cognitive imbalance for the learner and leads them to retrieve existing knowledge and try various combinations of schemes. The strength of the motivation to learn is determined by how far the person's current knowledge is from the subject matter they are about to study; if there is no gap, there is no need to learn, and if the gap is too large, it may be overwhelming. The other is the degree of social participation, that is to say, how much students are involved in the presentation process of their group plans. Such behaviour changes one's own sense of the need for process rules and thus affects the choices made at the decision-making stage later on[2].

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

There is a many-to-many mapping structure 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. Constraint conditions set for a project task (e.g., limits on the type of equipment or requirements for process concentration) directly correspond to the evaluation indicators of the course component "optimisation ability of the process scheme". The construction of the mapping relationship should meet the consistency condition; that is to say, the type of cognitive operation required by the project task should be isomorphic with the thinking process in the target ability, for example, the tolerance allocation ability needs a specific situation of dimensional chain calculation in its project task.

Based on the above analysis, the assessment system for the Project-Based Teaching Method can offer early warnings of any problems in students' learning at any time. The "process parameter adjustment ability" needed in this course is the same as the design of the comparison experiment for cutting speed and feed rate in the project iteration; learners will record the machining results of all parameter combinations and then reverse their initial selections. The mapping is bidirectional, and if there are any deficiencies in the course, such as the omission of the thermal deformation compensation rule, they can be found in the error analysis stage of the project task and thus serve as a diagnostic signal for learning weaknesses. The density of the mapping relationship shows how fully the teaching method covers the goals of the course; if the number of process decision-making nodes in the project task exceeds the number of core nodes required in the course ability list, then it can be considered that mapping has been achieved.

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

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

A chain of project tasks can help students link the links in their knowledge that were previously in different chapters of the course and gradually build up a problem situation. For example, in the whole chain of blank type identification, processing margin allocation and then cutting parameter determination, knowledge points such as material machinability, machine tool power constraints and tool wear laws all need to be employed in the same decision-making process. Serial connection does not organise knowledge according to attributes in a linear manner; rather, it is organised according to the timeline of process logic and explicitly shows the causal relationship among different parts of knowledge during task execution (e.g., how a change in feed rate affects surface roughness)[3].

The Aim of Structured Reorganisation is to reduce the interdependence of knowledge nodes. During the process of carrying out the project task chain, learners need to identify which knowledge points belong to the solution elements of the same process sub-problem and group them into functional knowledge modules. For example, when machining a shaft component, all the options in the "axial positioning module" can be used: What kind of centre hole should be used, which mechanical model for double-centre positioning should be employed, and how to adjust the rule for tailstock pressure; at the same time, the invocation weight of knowledge nodes that are not related to the current task in the original course system (such as general principles of non-traditional machining) is temporarily reduced. A module system can be introduced to organise the process knowledge of problem-solving in an orderly manner, and it is hoped that learners will be more motivated to organise their knowledge according to the characteristics of machining rather than following the sequence of textbook chapters.

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

There are many reasons for the construction of the process scheme, so learners need to consider all these factors in their work, such as the required accuracy, production speed and cost. Project-based teaching can have students organize their own studies, and through exploration, they will learn about the characteristics of machined parts; then, they can build a process sequence that meets the conditions for obtaining a clear scheme result and create complete process documentation cards. All the decision nodes (e.g., whether to separate rough machining from fine machining) need to call the corresponding process criteria (such as the principle of deformation control), and repeated invocation of such call operations strengthens the conditioned reflex association between rules and situations. It can be observed that the speed at which learners can recognise the boundary conditions for applying rules in new tasks has increased; for example, they will know which tolerance grade needs to be used for a semi-finished product.

The reinforcement path of the decision logic is also shown in the pruning method for invalid branches. Learners have a few choices for the initial plan or tool path, and then they will gradually eliminate the unfeasible ones according to the resource limitations of the project task (e.g., specifying the type of machine tool or tool inventory). Several times, students will need to put forward alternative plans, test the constraint conditions and eliminate rule-violating options in order to learn about the hierarchy of constraints. For instance, if the accuracy of the equipment is too low, we will not increase the cutting speed; instead, we will reduce the number of clamping sets in the process plan. The internalisation of the decision-making logic is portable; if the workpiece material is new or the batch-size requirement is different, the same constraint-prioritisation framework can be applied to adjust the plan without changing the decision-rule system[4].

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

As a result of some changes in the process parameters, a cognitive conflict occurs because there is a difference between the theoretical results of machining (e.g., the predicted surface roughness) that the learner calculated based on the initial parameters and the actual measured results. For example, if the turning parameters are as per the machining handbook, an unexpected vibration mark may appear during actual machining; this is because the recommended values in the handbook do not meet the actual stiffness of the process system. The degree of cognitive conflict is determined by how large the deviation is and what effect it will have in the next stage; when this deviation results in scrapping the workpiece, the intensity of the conflict is at its maximum. At this time, the learner has the most questions about the foundation of selecting the initial parameter, so it is necessary to reconstruct the cognitive schema.

According to the plan for hypothesis testing, a hypothesis test will be carried out. First, determine why it is out of specification; it may be tool wear, a lack of cutting oil, unreasonable cutting parameters, etc., and then change one parameter at a time and verify. For example, keep the cutting speed the same and reduce the feed rate to see if the vibration is gone; then you will have found the cause of the vibration. After several times, the student will be able to remember the parameter correction coefficients for a particular operating condition and use them to reduce the recommended feed rate by a safety factor of 0.6 in the turning of a slender shaft. The whole closed-loop process of conflict identification and hypothesis formulation to parameter adjustment verification will correct the parameter settings for the current task and form a good habit of using the recommended values in the process handbook. If the same conflict happens again, then the path length for adjusting the learner's parameters will be shortened; that is to say, some low-probability hypotheses will be skipped directly, and more attention will be paid to high-frequency sources of conflict based on past experience, such as giving more weight to clamping deformation than to 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 Indicators of the Retention Rate and Transfer Efficiency of Process Knowledge

The two indices of the extent of knowledge retention are the proportion of correctly identifying process knowledge and the accuracy rate in a delayed-test examination. The correct recognition rate is the number of essential process concepts (e.g., the six-point positioning principle and rules for machining allowance allocation) a learner can correctly identify at a certain time after completing a project task. The index is a closed-ended process scenario judgement question, and the distractors are in the same form but contain logical errors. To have a high reproduction accuracy, students should be able to write out the whole standard process route for a particular type of part (e.g., a rotating part) without referring to the original materials and match it with a template at the procedure level. The Degree of Match is determined by the consistency coefficient of the procedure order and the error rate of parameter values. The two indices can be given different weights and combined to form a general retention rate, and the weight coefficients are based on the importance of the knowledge point in the course objectives[5].

Transfer efficiency is how well a student can apply the learned process knowledge in various machining situations. The two are the initial decision-making delay time and the number of scheme revisions. The initial decision-making delay time is the length of time from the occurrence of a problem to the proposal of the first practical process plan for a new part drawing, and this index is negatively correlated with the efficiency of knowledge transfer. The number of scheme revision records how many defects in the learner's own scheme have been found during the process review session, and each revision is considered a case of knowledge backtracking behaviour. Set up a reference task (e.g., a simple stepped shaft) and a transfer task (e.g., a short shaft with an eccentric part), and then find the relative transfer efficiency. 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 smaller the information loss in the knowledge transfer process will be.

3.2 Error Tracing and Stability Judgment Criteria for Machining Implementation Accuracy

Error tracing of the accuracy of machining implementation is based on the deviation decomposition method of the machining result from the design requirements. Generally speaking, the whole deviation can be divided into several parts, such as position error, tool setting error, machine tool geometric error and thermal deformation error; these sections usually correspond to different decision points in the project work. For example, the position of the base of the workpiece directly affects the calculated value of positioning error, and as the range of process concentration is increased, so too will the accumulation of tool-setting errors caused by multiple clamps. A deviation transfer matrix is constructed to assign weights to all process decision nodes in the final accuracy index. The form of the output for error tracing is a contribution ranking list, and nodes with a large contribution (e.g., > 15%) are considered to be accuracy-sensitive nodes.

The standard for the stability judgment is the control chart of the repeated machining results. For the key dimension data (e.g., the outer diameter) in the same process scheme after several runs, a mean-range control chart is drawn and the upper and lower control limits are set. If all of the several consecutive sample points (e.g., 7 points) are on the same side of the centre line, or if one point falls outside the control limits, then it will be assumed that the process system is out of control according to this method. The reason for the unstable state can be traced back to some parameters in the process scheme, such as an overly large fluctuation range for cutting depth or incorrect setup of the tool wear compensation cycle. The other is the process capability index; it shows how well the output of the process scheme falls within the tolerance range. If the index is less than 1.33, it is assumed that the inherent variability of the process scheme exceeds the design tolerance range, and the safety margin of the process parameters needs to be re-evaluated.

3.3 Classification and Evaluation Criteria for the Innovation Level of Process Optimisation Behaviour

The degree of innovation in the behaviour of process optimisation is divided according to the combination of attributes of the optimisation object and the scale of optimisation. The first step of optimisation (parameter optimisation) is to change the continuous parameters of the current process plan, such as cutting parameters, tool geometric angle or coolant pressure, without altering the order of operations or the way of positioning. The size of the optimum is the reduction rate of machining time or the reduction amount of surface roughness. The second level of optimisation (procedure level) is to combine, divide or change the order of operations; for example, rough turning and semi-finishing can be done at the same time, or the order of heat treatment and finishing can be reversed. The third level of optimisation (principle level) is to use all kinds of machining methods, such as replacing turning with grinding, or to change the method of position by redesigning; for example, one can go from a single datum to over-positioning. The first kind of optimisation changes the basic logic of the process plan.

The foundation of the evaluation should be the construction of operational judgment norms at all levels of innovation. The foundation for parameter-level optimisation is the extent of the boundary extension for the parameter value range in the original plan; if the new parameter exceeds 30% of the recommended range in the original handbook and has been verified as feasible by actual machining, it can be considered a good improvement. To increase the level of procedure, we will reduce the number of procedures or the number of clamping set-ups after process concentration; a reduction of more than one clamping set-up will be considered to have met this requirement. For principle-level optimisation, it is based on the fact that the new machining method has not been recorded in the typical process documentation for similar types of parts, and this can be verified by comparing it with a standard process database. There are no conflicts at any level, and some kinds of improvements will need to change both the procedures and the parameters. First of all, we should avoid the problem of double counting in the evaluation at the top level.

Conclusion

Organize the knowledge points in an orderly way according to the process flow through a task chain, have learners create functional knowledge modules based on machining features, and change the original method of knowledge organisation from linear storage to that in textbook chapters. At the level of decision-making logic, repeated application of rules in the multi-attribute decision-making process and pruning of invalid branches are used to improve the decision-making chain for machining feature analysis and procedure sequence generation. As I have been adjusting the process parameters iteratively, there have been cognitive conflicts because the theoretical calculations do not match the actual measurements; according to the logic of hypothesis testing, I have developed a parameter correction strategy and thus formed a good habit of using the recommended values in the process handbook. The four links in the application effect mechanism of the above are: Weight synthesis of the correct recognition rate and the accurate reproduction rate is used to determine the rate of process knowledge retention; the ratio of the initial decision-making delay time to the number of scheme revisions is the index for transfer efficiency; error tracing of machining implementation accuracy computes the contribution of each decision node according to the deviation transfer matrix and signals nodes that exceed the threshold; stability judgment is based on the mean-range control chart and the process capability index, and values lower than 1.33 are considered unstable; finally, the innovation level of the process optimisation behaviour is divided into three tiers according to the optimisation object and scope: parameter level (adjustment of continuous variables), procedure level (merging of procedures or rearrangement of sequence), and principle level (introduction of heterogeneous machining methods or redesign of positioning schemes), each with its own operable judgment conditions established. The above is the entire analysis system of the application effect. In the future, we will continue to study the effect of all kinds of parts (such as box-shaped parts and irregular parts) on the topological structure of the project task chain and introduce a machine learning-based behaviour pattern recognition method for process decision-making. According to the path a student has taken in selecting and modifying parameters, dynamically change the evaluation items and give personalised diagnostic feedback.

Fund Projects

2025 Industrialization Project of the Jilin Provincial Department of Education (JJKH20251901CY)

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