Innovation in the Practical Teaching Mode of CNC Machining Based on the Cultivation of Engineering Ability

Banglang Chen*

Hainan Vocational University of Science and Technology, Haikou, 571126, China
**Corresponding author: 15076631686@163.com*

Abstract: *As the manufacturing industry is changing to be more digital and intelligent, higher demands will be placed on the systemic abilities of engineering talents. The traditional structure and environment of teaching CNC machining do not promote the development of students' engineering problem-solving abilities. A New Teaching Model for CNC Machining Based on Cultivating Engineering Ability is Proposed in this paper. First, according to the main factors of engineering ability and the systematic features of CNC machining teaching, an ordered mapping method between ability orientation and teaching content is established. Secondly, due to the deficiencies of the traditional linear teaching model, a path for the transformation of teaching design is proposed that is driven by the evolution of technology and aims to achieve the integration of abilities. Finally, the whole framework of the three-dimensional innovative model will be used to set all the levels of ability goals, the virtual-and-real integrated teaching environment, and the continuous-improvement evaluation mechanism. The model can help students apply what they have learned in daily life, develop all kinds of skills through practical experience, and provide a theoretical foundation and practical basis for all-round reform of teaching in higher vocational education.*

Keywords: *Engineering Ability, CNC Machining, Teaching Mode Innovation, Virtual Reality Integration, Ability Assessment*

Introduction

The main problem in engineering education now is how to turn particular technical knowledge into an organised ability for students to solve all kinds of engineering problems. Traditional teaching of CNC machining is generally in the form of theory first and then practice, has disjointed sections of knowledge, and lacks an engineering context. Therefore, it is not feasible to promote the development of modern engineering ability effectively, as it is based on design thinking, system integration and innovative decision-making. It will be difficult to teach well, and we will fail to foster the talent required by the changes in society's needs for the industrial era. Therefore, exploring new ways to carry out the practical teaching mode of CNC machining is of great theoretical and practical value. Deconstruction of the Connotation of Engineering Ability and Characteristic Analysis of the Teaching System are the starting points of this study. It hopes to build a teaching model that can promote the deep transformation of knowledge into ability and is suitable for the context of intelligent manufacturing; thus, it systematically reconstructs teaching objectives, the teaching environment and assessment methods to offer a systematic solution to the problem of improving the quality and deepening the connotation of engineering practice teaching.

1. Theoretical Correlation between the Connotation of Engineering Ability and CNC Machining Teaching

1.1 Analysis of the Main Components of Engineering Ability

The components of engineering ability are all connected and belong to various levels of cognition and application. The first type of basic ability is systematic cognition; it is founded on mathematics, natural sciences and engineering sciences. The first is that abstract theories and models can be used to study the necessary conditions and restrictions of a complex technical system. In addition to the first, the second is the design-implementation ability for engineering practice. It means that all links in the technical integration and materialisation process have been completed, and it has met the required conditions and resource limitations. The first is the development of technical solutions, and the second is how to deal with all sorts of limitations, such as cost, time, performance and reliability, and what to choose.

With the increase in complexity of modern engineering work, practitioners must develop good cooperation and self-management skills. It includes the ability to cooperate and communicate effectively with people from different fields, coordinate resources, manage the process of a project, and use reflection to monitor, evaluate and adjust one's own thinking. Metacognition helps engineers recognise the core of a problem, plan how to solve it, judge the results of the plan, and modify the plan when necessary. All of the above dimensions together constitute an active, interrelated and tiered system of abilities. It is not a set of fixed knowledge, but a portable mode of thinking and acting to solve problems in uncertain situations. The above framework presents a clear range of competencies for the aim setting of special education teaching, and thus, instructional activities should go beyond the simple transmission of knowledge to cultivate such a compound and reflective professional ability[1].

1.2 Analysis of the Systemic Characteristics of CNC Machining Teaching

As the representative subject of technical education, the teaching system for CNC machining will naturally be characterised by technological integration and process closure. The teaching content will naturally cover many subjects, such as mechanics, materials science, computer programming, automatic control and measurement technology, etc. The links in the entire production chain of the teaching process are analysis of part drawings, process planning and machining program preparation, machine tool operation, and finally, quality inspection of the finished product. Therefore, the teaching should not present individual pieces of knowledge in isolation; instead, a cognitive and practical environment should be created that can demonstrate genuine technological integration and process logic. It is a relatively small, controlled model of an engineering system in fact. The teaching value is that students will learn about the whole process of change from an abstract design demand to a real object.

It is also quite interactive and will respond to commands in a timely manner. The three teachers will cooperate to lead the students in learning. The students' choices will directly determine the CNC code of the machine, and the machining results will show us whether their previous decisions on process and program were correct. A closed-loop system of "decision-implementation-feedback" can be established to obtain the actual results of teachers' teaching activities and promptly correct any problems. All Machining attempts will result in permanent deformation of the material and are therefore not suitable for study. Prompt, objective and embodied feedback can create a special atmosphere for cultivating engineering judgment and a sense of responsibility; it is a necessary condition for good teaching that is difficult to achieve in other ways.

1.3 The Mapping Mechanism of Ability Orientation and Teaching Content

The aim of the mapping method for cultivating ability is to link the general ideas of ability with specific content in the teaching materials. First, we will decompose the knowledge system of CNC machining and then reconstruct it. Based on the "cognition-design-implementation-collaboration" ability framework, the old content modules focused on equipment and operation have been changed into task sequences based on the chain of engineering problems. For example, in the lesson "programming commands", they fall under the Design Context of "realising a process plan for specific geometric features and precision requirements"; thus, Design Thinking and systematic trade-off skills can be naturally incorporated into the teaching of knowledge. A map can be used to divide the ability goal into several specific teaching activities, show various cognitive difficulties, and explain how to achieve this ability[2].

The purpose of the above mapping is to form a cycle of knowledge application and gradually increase the cognitive load. The Design of teaching content should offer many chances for learners to experience the whole cycle of "requirement analysis - scheme formation - programme implementation - result verification - reflection and optimisation", and gradually add more complex constraints to this cycle, such as efficiency, cost and multi-process coordination. Therefore, the study of technical knowledge and the development of engineering ability will no longer be done separately. In the course of gradually solving more difficult problems, there will be internalisation, integration and transformation of knowledge. A spiral shape can help the students study independently and solve problems in this way. Finally, a stable mind-set and behaviour model that can be applied to all areas of engineering will be established, and we will move from "know-how" to "competence".

2. Limitations of the Traditional Teaching Mode and Paths for Innovation

2.1 Assessing the Effectiveness of the Current Teaching Structure

At present, the teaching structure for CNC machining is generally a linear sequence model of "theoretical instruction - skills training". Modules of theoretical teaching cover knowledge of CNC principles, code syntax and process parameters, etc.; the purpose of the experimental or practical training stage is to enable students to learn machine tool operation procedures and repetitive machining of fixed workpieces. The division above is the same in terms of time and place. Therefore, students' knowledge of CNC technology is still at the level of functional cognition; they have not formed a deep understanding of the integrity of the manufacturing system, the chain of process decision-making, or the trade-offs among various solutions under multiple constraints. Its more serious defect is that it assumes a single, standard way of learning skills and fails to consider the uncertainty and exploration in engineering design.

Further research has found that the main problems of the above structure are the division of knowledge modules and the lack of an engineering context. The parts of the teaching are independent and can be learned separately; for instance, programming, operation and measurement are taught in different courses or teaching modules. The above will break the strong coupling and iteration of all the parts in the actual engineering work. After finishing one part, students' thinking suddenly stops, and they are unable to carry over what they have learned in that part to check or correct it in the next one. Therefore, it is difficult to cultivate good engineering ability in fractured and decontextualised teaching activities, such as systems thinking, problem definition and overall problem-solving, and the transferability of learning results is relatively low[3].

2.2 The Driving Force of Technological Development in the Teaching Paradigm

New-generation information technology, such as digital twins, virtual simulation, the industrial Internet and intelligent programming, is changing the technological environment of manufacturing in many ways. The design and production of products will be changed by these technologies, and new demands will be placed on the competence structure of technical staff in the industrial era. With the development of intelligent manufacturing, professionals need to have good traditional machining skills and also be able to learn other skills such as cross-domain model construction, data-driven decision-making and interaction between virtual and physical systems. This is the main reason for the development of the teaching model. The old training model for the ability of equipment operators can no longer meet the demands of the future manufacturing system, so we need to train talent with skills in digital modelling, process optimisation and autonomous decision-making.

Changes in technology have provided some direct tools and new ways to help reform education at present. High-Fidelity Virtual Simulation and Digital Twin technology can create a safe, low-cost and highly flexible digital manufacturing environment. Therefore, all kinds of process plan verification, collision detection, program debugging and performance prediction can be carried out by students without the need for physical equipment and materials. The problems of physical resources, time and place can be resolved, and a fast iterative cycle of "Design-Simulation-Optimisation" will be established. Teaching technology is no longer limited to setting up copies of physical equipment; now, systems have begun to be developed that can train students' abilities in digital modelling, analysis, prediction and optimisation at any time during the production process. It will shift the direction of teaching from skills training to the cultivation of engineering thinking and innovation.

2.3 Change in Pedagogical Design towards Ability Integration

To overcome the shortcomings of the traditional model and meet the demands of technological changes, the main direction of pedagogical design is now building a new framework for ability integration. Therefore, the starting point of teaching design is no longer to cover all the knowledge in the curriculum, but rather to integrate and present the necessary theoretical knowledge, technical skills, tools and methods, as well as non-technical competencies such as collaboration and communication, by taking typical, progressive engineering tasks or projects as the medium. The goal of teaching has changed from "knowing what" and "being able to operate what" to "at what level of complex engineering problems can one be comprehensively solved by integrating knowledge and resources", focusing on the emergent and holistic nature of ability[4].

Therefore, in order to build a good foundation for teaching design, we need to develop all-encompassing learning task sequences that are reasonably challenging, open-ended and authentic. The above sequences should imitate the ambiguity, multi-objectivity and iterativity of real engineering problems, enabling students to go through the whole closed-loop process of requirements analysis, scheme design, program implementation, virtual verification, physical processing, quality assessment and iterative optimisation. The traditional divisions of knowledge have also been incorporated. Now, rather than being separate learning objectives, the knowledge components of mathematical calculation, material mechanics, computer programming and precision control are necessary conditions and essential means for carrying out tasks. Therefore, the entire teaching process is a construction of knowledge, and under guidance, students will be able to learn independently, collaborate in decision-making, and reflect. Thus, in the face of real technical problems, many types of engineering abilities are stimulated, integrated and coordinated at the same time.

3. Systematic Construction of an Innovative Teaching Model for CNC Machining

3.1 Structured Design of Multi-level Ability Objectives

The first is that the goals of an innovative teaching model should be in line with the different stages of development of students' engineering literacy. The Structure of the multi-level ability objectives is a ladder of abilities, and at the top is all-round innovation. First, one should learn the general ideas of CNC systems, basic manufacturing processes and programming languages; next, use these tools to plan and carry out the production of a particular part in a simulated or simplified environment, thus developing basic system integration and troubleshooting skills; finally, the highest goal is to design new solutions, handle multiple objectives and trade-offs, and manage the entire process of complex, open-ended engineering problems under various constraints. The goals of all the above levels are not in opposition but rather cooperate to promote learning, and the automatic skills learned at the lower levels provide a foundation for high-level creative thinking.

The problem of a single skill goal in the old model has been solved; now, every teaching unit or project task knows its position in the whole competency system and how to be supported and transitioned among different levels of ability. The Design Process should specify concrete, observable and measurable teaching behaviours and results for the general descriptions of abilities, such as "analysis", "design" and "optimisation". General optimisation ability refers to adjusting one machining parameter to improve the basic level of surface roughness; more broadly, it is to achieve all sorts of goals and make them work together, such as material utilisation, efficiency, cost control and equipment load. By setting out the goals in an organised and progressive manner, the teaching process will be an organised set of learning aims that are gradually achieved, combined, absorbed and practised by the students; thus, they will be able to reach their learning goals[5].

3.2 Integration of Virtual and Physical Teaching Environments and Resource Allocation

In order to achieve the above goals of ability, an entire-school teaching environment should be created that removes physical barriers and expands the horizons of cognition. First, a single virtual and real environment need be built so that people can interact with the machining system in real time and have two-way data exchange. High-precision simulation software and a digital process platform in a virtual environment can be used for all sorts of purposes, such as checking the feasibility of a process, risk-free program debugging, machining process prediction, etc.; they can quickly try out many solutions and expand the scope of exploration and error tolerance in learning. The external world has materials, forces and heat; it is also possible to verify the final product here, so people can learn by doing and develop an intuitive sense of uncertainty. The two environments are connected by a single digital thread to form an augmented cognitive loop; that is to say, virtual prediction leads to physical operation, and then the actual results are used to improve the virtual model.

The Logic of resource allocation should be revised in light of the above; that is to say, it will shift from equipment-centric to data-and-taskflow-centric. According to the demands of the teaching plan at different times, all kinds of hardware resources (such as CNC machine tools and measuring instruments) and software resources (such as CAD/CAM, PLM, simulation cloud platforms) will be organised and integrated flexibly to build a technological ecosystem that supports a fast cycle of "virtual experimentation - physical validation". First, there should be only one window for data management and interaction, and all links in the process must be digitally connected and traceable, from 3D models and process sheets to CNC code and machining feedback data. Collect all the data on students' learning progress, choices, etc., at any time to provide individualised study guidance and accurately assess their learning. Therefore, the aim is no longer to carry out the basic operations but to build a foundation for deep learning. It will continue to provide a supply of data and help to build a good foundation for the students' future studies in an efficient manner.

3.3 Continuous Iterative Teaching Evaluation and Optimisation Mechanism

A new teaching model with life should have a set of evaluation and optimisation mechanisms to promote its self-improvement. Firstly, it is no longer a single-point, summative assessment but rather a collection of various sources and continuous observations of children's abilities. The evaluation data is no longer restricted to the final workpiece and test papers; it can now also be obtained by collecting the students' simulation iteration records in the virtual environment, their process decision-making logic, operational sequence and exception handling during physical processing, communication logs in project collaboration, and reflective reports at all times during the process. All these types of data combined can show us how students' abilities have changed and how they think in the process of learning.

Based on the above data foundation, the optimised mode is a closed-loop system of: "evaluation - diagnosis - correction - redesign". According to the performance data of individual students and groups at all levels in the competency spectrum, particular bottlenecks in the teaching process that hinder the achievement of goals, task suitability or support effectiveness can be identified. Therefore, the optimisation interventions are quite specific, and they can take the form of adjusting the difficulty gradient of a virtual simulation task, adding supplementary micro-lecture resources for a certain area of knowledge, or changing the guidance strategy for team projects. Therefore, the teaching model is now an adaptive system that can respond to changes in students' learning at any time. It promotes the development of teaching design in a dynamic and generative manner, and its effectiveness for students continues to increase with changes in technology, other schools, etc. It will be suitable for the long run, relevant in our times, and has been developed into an evolving professional teaching model.

Conclusion

Based on the analysis of theory and problems above, this paper will put forward a new practical teaching model for CNC machining to foster students' engineering ability. Based on a good Design of multi-level ability objectives and with the full support of a well-integrated virtual-actual teaching environment, continuous iteration and improvement will be carried out according to all kinds of data to build the tripartite teaching structure of objectives-environment-mechanism for this system. It can solve the problems of linearization and fragmentation in traditional teaching, promote the integration of knowledge learning and ability construction, and introduce engineering knowledge. The following will be the directions of future research: First, how to incorporate digital twin technology more deeply into the closed-loop teaching cycle and what learning effects can be achieved through it; Second, how to build a more adaptive recommendation system that personalises the path of ability development according to learning analytics; Third, verification of the transferability and scalability of this model to other clusters of engineering training courses. Innovations in teaching models are constantly emerging; therefore, to continue enhancing the quality of engineering talent education, we must keep pace with changes in technology and new ideas in education at the same time.

References

[1] Xiao, H. J. "Analysis of Practical Teaching in CNC Machining Courses." Integrated Circuit Applications 42.09(2025): 230-231.
[2] Du, J. S. "Practical Research on the 'Theory-Practice Integration' Teaching Model in Secondary Vocational CNC Machining Majors." Auto Time .02(2025): 85-87.
[3] Li, T. Y., and Zhao, F. "Reform and Practice of CNC Machining Practical Teaching under the Background of Intelligent Manufacturing." Die & Mould Manufacture 24.09(2024): 50-52.
[4] Sun, G. J. "Curriculum Reform and Practice of CNC Machining Technology Based on Engineering

Practice." Die & Mould Manufacture 24.03(2024): 103-105.
[5] Lin, D. Y. "Research on the Construction of CNC Machining Practical Training Courses Based on Engineering Ability Cultivation." Scientific Consultation (Science & Technology Management) .19(2021): 105-106.