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Research on Curriculum Reform of Fundamentals of Mechanical Manufacturing Technology Based on OBE Theory and Competency Map

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Abstract: To address the new requirements for mechanical engineering talents raised by intelligent manufacturing, the curriculum reform of Fundamentals of Mechanical Manufacturing Technology based on OBE theory and Competency Map has been explored. This paper verifies the feasibility of applying the teaching paradigm combining OBE theory and Competency Map to the course construction firstly. Then, the "Knowledge-Analysis-Design / Comprehensive-Practice" four-dimensional integrated course objective is proposed based on the OBE theory, the training model integrating theoretical teaching, experimental teaching and practical teaching is reconstructed by introducing project-based teaching methods, the blended teaching approach of online and offline that organizes teaching activities through online learning, classroom teaching, flipped classrooms and other means is established, and the diversified and intelligent educational teaching evaluation system based on big data is built. Finally, on the basis of the above-mentioned curriculum reforms, a competency map is established. This effectively connects the path from knowledge internalization to ability generation of students, providing theoretical basis and reference for the reform of the "Fundamentals of Mechanical Manufacturing Technology" course in the context of intelligent manufacturing.

Keywords: Mechanical Manufacturing; OBE; Competency Map; Curriculum; Reform

1. Introduction

In the wave of global technological revolution and industrial transformation, technologies in the fields of artificial intelligence, information communications, new materials, and new energy continue to make major breakthroughs, and are deeply integrated with advanced manufacturing technologies to produce a series of advanced manufacturing models such as integrated manufacturing, additive manufacturing, and intelligent manufacturing. At the same time, the international environment has become increasingly complex and changeable, and competition in global science and technology and industry has become increasingly fierce. Building a manufacturing power has become a new focus of strategic games among major powers. As the core form of Industry 4.0, intelligent manufacturing can achieve a qualitative improvement in productivity and has become the primary focus for building a world-leading manufacturing country. Currently, the transformation and upgrading toward intelligent manufacturing is largely restricted by the shortage of high-end manufacturing talents proficient in digital, network and automation technologies [1-3]. Mechanical majors are the majors most closely integrated with manufacturing, and there is an urgent need to cultivate high-end manufacturing talents. Fundamentals of Mechanical Manufacturing Technology is the main professional core course of the Mechanical Engineering major. It is an applied technical discipline that takes process issues in mechanical manufacturing as their research object. Their traditional teaching model and content cannot adapt to the working model and organizational form of process manufacturing in an intelligent manufacturing environment [4-7]. In order to promote the transformation and upgrading of traditional manufacturing and the development of intelligent manufacturing, we explore the reform of basic education and teaching of mechanical manufacturing technology under the background of intelligent manufacturing, form a new teaching model that adapts to social needs, and cultivate high-end talents who meet the needs of intelligent manufacturing, which is of great significance to the transformation and upgrading of the manufacturing industry [1-4].

Based on the background of intelligent manufacturing, this article analyzes the development status of the machinery manufacturing industry and the construction of Fundamentals of Mechanical Manufacturing Technology and the necessity of curriculum reform. It discusses the feasibility of integrating OBE (Outcome-Oriented Education) theory and Competency Map in the construction of Fundamentals of Mechanical Manufacturing Technology. Based on the characteristics of the OBE theory and Competency Map teaching model, the construction of Fundamentals of Mechanical Manufacturing Technology was explored and thought from the aspects of course objectives, practical link settings, online and offline teaching models, and multiple teaching evaluations, and a method of constructing the Competency Map of the course based on the OBE theory was designed, aiming to provide theoretical basis and reference for the reform of the Fundamentals of Mechanical Manufacturing Technology in the context of intelligent manufacturing.

2. Necessity of Reform for Fundamentals of Mechanical Manufacturing Technology

2.1 Development Status of Mechanical Manufacturing Industry in China

China has achieved fruitful results in intelligent manufacturing. First of all, intelligent manufacturing equipment (such as additive manufacturing equipment, industrial robots, high-end CNC machine tools and other digital manufacturing equipment) has met 50% of market demand. In addition, 285 domestic standards for intelligent manufacturing have been issued, and 28 international standards have been led and formulated by China. However, there are still many unresolved problems in achieving high-quality development. The key problems are mainly focused on the low adaptability of digitalization and intelligence in the manufacturing industry and the lack of professional talents. The cultivation of intelligent manufacturing-related talents is the key to high-quality development [7-9]. Mechanical professionals are the technical pillar of the manufacturing industry and a comprehensive reflection of the country's scientific and technological level. In the context of intelligent manufacturing, the design, manufacturing and maintenance methods of mechanical products have undergone major changes. Mechanical processing equipment has become more intelligent and integrated. Mechanical professionals need to master new design and manufacturing processes and possess knowledge in multiple fields such as automatic control, electronic technology, information technology and artificial intelligence. The skills required to process and maintain intelligent equipment [3,7,9].

The process manufacturing teaching model of traditional mechanical majors has lagged behind industrial development. In the process of industrial upgrading, how to cultivate compound mechanical manufacturing talents who ""Understand Theory, Can Analyze, Can Design, and Good at Practice" to meet the needs of intelligent manufacturing is a major theoretical and practical issue facing the development of modern high-end manufacturing [9-11]. The teaching of relevant courses in mechanical majors should follow the concept of "Adapting to Industry Changes and Facing Future Trends", combined with artificial intelligence technology, and optimizing and upgrading the structure of relevant courses to cultivate diversified innovative talents. This is a necessary step to promote educational reform and meet the needs of social development [5].

2.2 Current Status of Construction of Fundamentals of Mechanical Manufacturing Technology

2.2.1 Course content lags behind

Fundamentals of Mechanical Manufacturing Technology is the main core course in mechanical majors based on the process issues of mechanical manufacturing. Their main contents include metal cutting principles, machining equipment (applications of various machine tools and cutting tools), analysis and design of machine tool fixtures, basic theoretical knowledge of machining technology and assembly technology, machined surface quality, etc. It has the remarkable characteristics of numerous knowledge points, strong cross-cutting, and strong theoretical and practical aspects. The goal of the course is to enable students to analyze and solve quality problems encountered in manufacturing and assembly, and to have a certain understanding of the development trends of machining processes. There is a lot of teaching content in the course, but the current undergraduate education course hours are constantly being compressed, and there is less teaching content that combines intelligent manufacturing technology, intelligent equipment and intelligent technology. In addition, the combination of laboratory construction and intelligent manufacturing is insufficient, the experimental teaching content is limited to traditional content such as tool measurement and the stiffness of machine tools, and students lack sufficient cognition of intelligent processing equipment [6,11]. For mechanical processing equipment to become more intelligent and integrated, mechanical professionals need to master new design and manufacturing processes, and have knowledge in multiple fields such as automatic control, electronic technology, information technology, and artificial intelligence. The skills required to process and maintain intelligent equipment [10].

2.2.2 Teaching method model

The teaching of Fundamentals of Mechanical Manufacturing Technology generally follows a traditional lecture-based, teacher-student interactive model. Students adopt a passive learning mode with low classroom participation and learning initiative. They lack initiative in learning and have low interest in learning. The learning effect or achievement evaluation mechanism is mainly based on single-dimensional scores, which cannot reflect the comprehensive quality of students. In the context of the artificial intelligence era, it is necessary to establish a multi-dimensional, procedural and scientific evaluation mechanism for students, and an education and teaching evaluation system that reflects students' innovative abilities and ability to solve practical problems [6,10].

2.2.3 The disconnect between theory and practice

According to the professional training plan, students majoring in mechanical engineering will undergo engineering training in their sophomore year. They will learn about basic mechanical processing equipment and processes (ordinary machine tools, Computer Numerical Control (CNC) machine tools, metal cutting, welding, and blank production), which belongs to the general education of engineering. The production internship of the mechanical major is arranged after the course, and the relevant course knowledge has been forgotten and cannot be sublimated. The students' prerequisite courses involve limited content in mechanical manufacturing, and they lack understanding of mechanical manufacturing, which is not conducive to cultivating students' ability to analyze and solve mechanical manufacturing problems. The construction of the teaching team also needs to be paid attention to, cultivating teachers' interdisciplinary abilities and the ability to connect with the industry to adapt to the teaching needs of the intelligent manufacturing era. In short, the intelligentization of manufacturing has had a multifaceted impact on the teaching of mechanical majors, and teaching reform is needed to adapt to and lead the development trend of intelligent manufacturing.

2.2.4 Single assessment and evaluation mechanism

The course evaluation of student learning effects still uses traditional theoretical examinations as the main assessment method, with a smaller proportion of practical links. The experimental links are still mainly based on verification experiments such as the measurement of tool angle and the measurement of machine tool stiffness, and students' practical abilities are evaluated in the form of experimental reports. This traditional assessment and evaluation method cannot reflect students' ability to analyze and solve mechanical manufacturing problems, and is not conducive to cultivating students' engineering practice ability and innovation ability [6-7,10-11].

3. Integration of OBE Theory and Capability Mapping

3.1 OBE Theory

The OBE concept can transform the traditional subject-oriented orientation into the orientation of learning outcome output. Their specific principles are: combining social and economic development and industrial needs, clarifying the abilities and qualities that graduates should have, and designing the curriculum system, teaching content and evaluation methods accordingly; taking students as the center, emphasizing the main role of students in the learning process. It advocates students' independent learning, self-evaluation and mutual evaluation; teachers are managers, demonstrators and supervisors of the teaching process, evaluate students' self-study, promote students' independent learning ability and practical exploration ability, and are conducive to students' long-term development; establish a dynamic feedback mechanism to continuously optimize teaching links based on multiple evaluation data [12]. This theory emphasizes the high matching between educational output and industrial demand, and is highly consistent with the inherent requirements of talent training in the era of intelligent manufacturing.

3.2 The Concept and Function of Competency Map

Competency Map is a structured and visual tool that uses artificial intelligence technology and analysis methods to describe the professional abilities and internal structural relationships required by individuals to be qualified for positions in specific fields. In mechanical industry education, Competency Maps can provide directional guidance for the cultivation of universally applicable core skills or professional skills in specific fields [13,14].

3.3 Integration of Teaching Concepts and Teaching Tools

The OBE theory advocates the reverse design of teaching logic based on expected learning outcomes, corresponding to knowledge input and ability output, which can achieve a high degree of matching between educational output and industrial needs. However, when designing teaching based on OBE theory, we will face how to transform the macro principle of "ability output" into executable daily teaching behaviors and evaluation ability levels. Ability mapping is a structured tool for implementing this concept. It decomposes abstract abilities into an observable and evaluable indicator matrix, and clearly links teaching activities and evaluation indicators [14]. The core advantages of combining the two are: first, precision - transforming vague learning results into specific competency indicators and rubrics, moving evaluation from a single model to data-driven real-time feedback and an intelligent teaching model of continuous improvement; second, autonomy-using a visualized ability path to guide students to self-diagnose and adjust learning, truly implementing "student-centered"; third, systematization - achieving hierarchical mapping of course objectives, professional graduation requirements and social industry standards, opening up "curriculum islands", and forming a traceable and alignable ability training chain. The combination of the two is essentially a key step for educational design to move from "top-level theory" to "practical tool" [15-17].

Fundamentals of Mechanical Manufacturing Technology is particularly suitable for this model because the course content covers metal cutting principles, machine tool fixtures, process procedure design, machining accuracy analysis, etc. The knowledge points are complex and highly practical. In traditional teaching, students tend to fall into fragmented memory, but it is difficult to develop real process design abilities. The "OBE + Competency Map" aims at specific outputs such as "being able to independently prepare machining process procedures for medium-complex parts". It breaks down capabilities such as process plan formulation, machine tool and tool selection, positioning error calculation, and quality control into trainable indicators, which directly correspond to project tasks (such as process design, fixture disassembly and assembly, and error case studies). This course is inherently "engineering problem oriented" and is an ideal candidate for the implementation of the OBE theory and Competency Map teaching model.

4. Curriculum Reform Model

4.1 Course Goal Refining

Based on the OBE concept, with the goal of cultivating high-quality innovative talents with engineering practical ability and innovation ability, combined with graduation competency requirements of the indicator points 1.3, 1.4, 3.1, 3.2 and 11.1 for the mechanical Engineering major at Yangtze University, market demand and school advantages of the Mechanical Major, coupled with national strategies and regional economic development needs, the four-dimensional integrated curriculum goal of "Knowledge-Analysis-Design/Comprehensive-Practice" is constructed, as shown in Figure 1. The course objectives meet the requirements of engineering education certification for the ability to solve complex engineering problems, and also meet the complex demand for mechanical talents in the era of intelligent manufacturing to "Understand Theory, Can Analyze, Can Design, and Good at Practice ". After studying this course, students should be able to (Knowledge level): systematically explain the basic concepts and theories of metal cutting principles, machine tools, cutting tools, fixtures and process procedure design. (Analysis level): For a given part drawing, analyze their technical requirements and select reasonable processing methods, machine tools, tools and cutting parameters. (Design/Comprehensive level): For a medium-complexity part (such as a stepped shaft, gear box), formulate their machining process procedures, including process routes, process cards, etc. (Practical/evaluation level): In experimental environments and actual operations, be able to correctly operate basic machine tools (such as lathes and milling machines), process simple parts, and be able to measure and evaluate processing quality (accuracy, surface roughness).

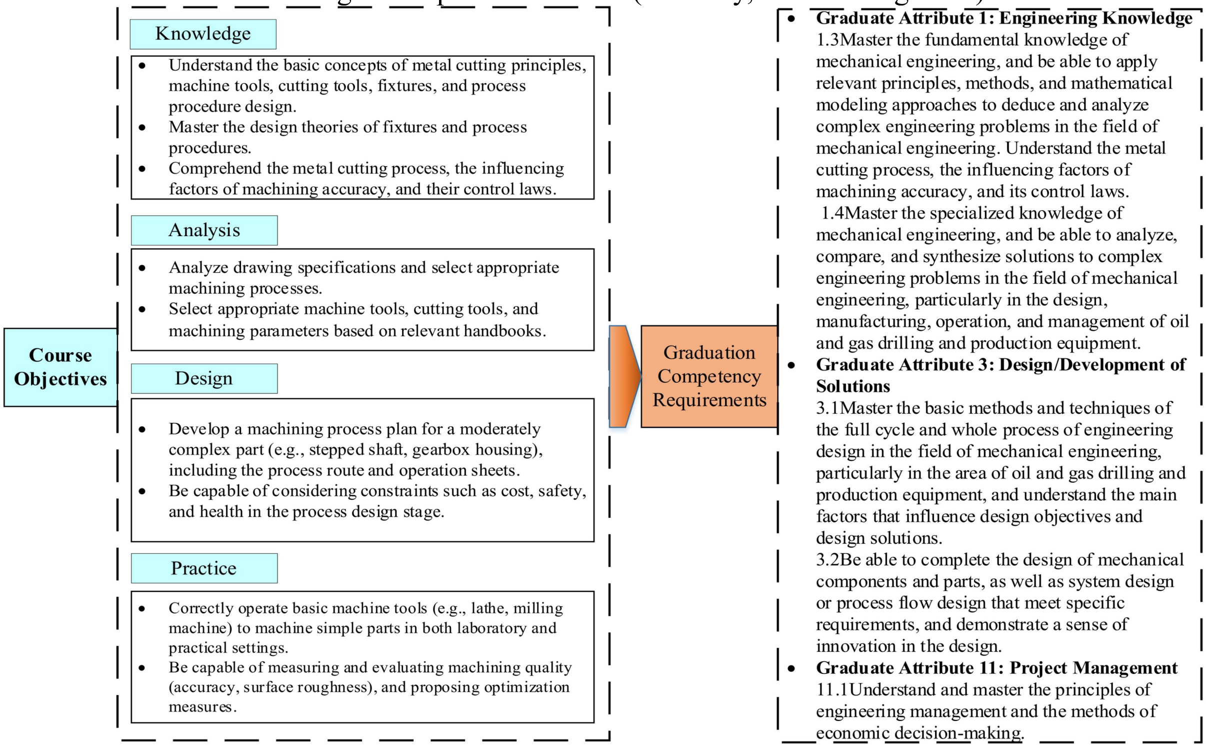

Figure 1. OBE-oriented Course Objectives of Fundamentals of Mechanical Manufacturing Technology

4.2 In-Depth Integration of Practical Aspects

Fundamentals of Mechanical Manufacturing Technology is an applied technical discipline that takes the process issues in mechanical manufacturing as their research object. It is a bridge connecting theoretical foundations and engineering practice. The current basic classroom teaching of Fundamentals of Mechanical Manufacturing Technology is independent of practical links such as course design, experimental teaching, metalworking practice, and production practice, resulting in a disconnect between theoretical links and practical links. For the Fundamentals of Mechanical Manufacturing Technology, it is necessary to systematically integrate the four major links of course design, experimental teaching, metalworking internship and production internship, follow the progressive logic of skill foundation, analysis deepening, and practical application, and form a training model that integrates theoretical teaching, experimental teaching and practical teaching, as shown in Figure 2.

Course teaching: Complete the reserve of basic professional knowledge and master basic design analysis methods and concepts. Course design: Cultivate students to use the basic knowledge of mechanical manufacturing technology and related courses (engineering materials, mechanical design, interchangeability and technical measurement, metal cutting principles and tools, etc.) to independently analyze and solve process problems, and initially have the ability to formulate process procedures for complex parts. Experimental teaching: focuses on principle verification and data analysis, simulates part processing through a virtual simulation platform, and designs new experimental projects such as "machining process vibration monitoring" and "cutting parameter optimization simulation" to cultivate students' data-based analysis and decision-making abilities. In addition, experimental teaching needs to be combined with intelligent manufacturing technology to build intelligent laboratories and training bases to provide students with a platform for practice and innovation.

Metalworking internship: Strengthen basic skills training and engineering literacy, and build a perceptual understanding of advanced manufacturing technology by increasing the proportion of modern manufacturing technologies such as CNC machining and 3D printing on the basis of traditional turning, milling, planning, and grinding. Production internship: By going deep into the manufacturing enterprise, participating in the actual production process, understanding the execution of process procedures, production organization management and manufacturing system integration, and completing the leap from skills training to systematic thinking.

The specific approach adopts the introduction of project-based teaching methods, and promotes students to apply basic theoretical knowledge, the ability to formulate process procedures and basic processing skills to real scenarios by designing real parts processing projects that are closely related to practical production problems. By solving complex problems in these projects, students are guaranteed to master and apply professional knowledge while stimulating their creativity and independent learning abilities, cultivating their innovative and research thinking, and exercising teamwork and communication skills [15].

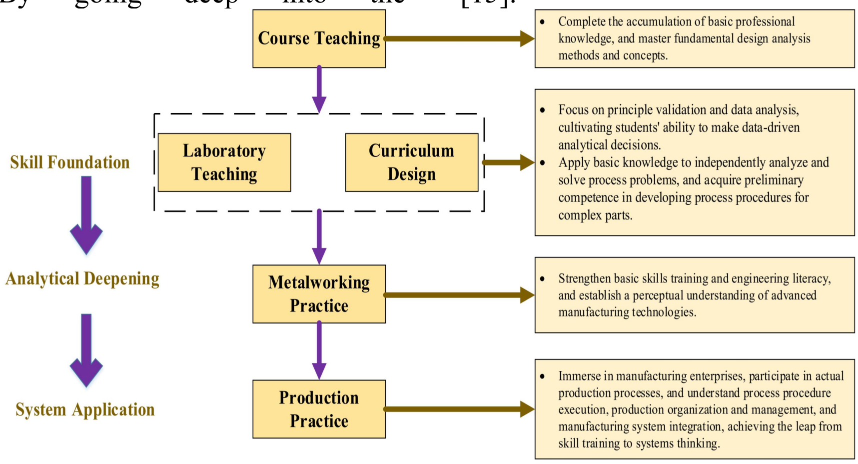

Figure 2. A Training Model That Integrates Theoretical Teaching, Experimental Teaching and Practical Teaching Mode

4.3 Online and Offline Blended Teaching

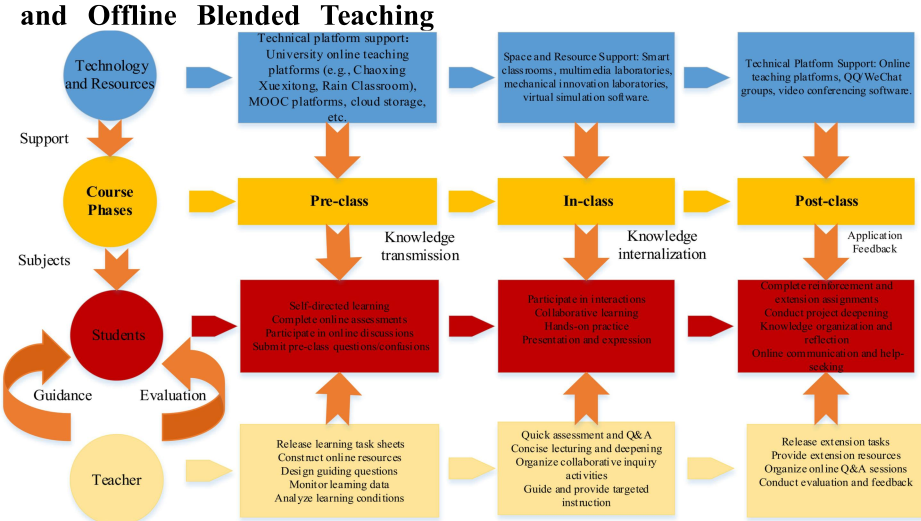

Figure 3. Blended Teaching Model

The blended teaching model organically combines online learning with traditional classrooms, with students as the main body, which can stimulate students' independent learning abilities and break the traditional time dimension. Teachers play the role of guidance and evaluation, giving full play to the leading role of teachers. From the time dimension, the course is divided into three stages: before class, during class and after class. From the content dimension, the course content is divided into online independent learning before class, offline discussion during class, and online or offline development after class. The specific model is shown in Figure 3. This course will use online learning, classroom teaching, flipped classroom and other methods to organize teaching activities.

The specific methods are as follows: Pre-class teacher activities: (1) Publish a learning task list before class to clarify the learning objectives, key points and difficulties of the week, and online tasks to be completed; (2) Build online resources to record or select micro videos (such as turning principles, fixture positioning principles, etc.), upload PPT, documents, technical standards, classic papers, etc. (3) Secondly, publish online tests and discussion questions on the Rain Classroom platform to design guiding questions to stimulate students' thinking. (4) Check students’ video viewing completion rate, test scores, and forum participation through the platform. Student activities: (1) Independent learning, watching micro-lecture videos and reading relevant materials according to the task list. (2) Complete the simple online test through Rain Classroom to test the mastery of basic knowledge. (3) Participate in online discussions, ask questions during preview in the course forum, or answer questions from teachers/classmates. (4) Submit doubts before class: Summarize and submit questions that cannot be solved during self-study.

Teacher activities for online and offline teaching interaction (knowledge internalization) during class: (1) Quick assessment and Q&A. Use the first 10 minutes of class to check the preview effect through voting, asking questions, etc., and focus on answering common questions. (2) Concise teaching and deepening: no longer explain basic knowledge repeatedly, but focus on core concepts, internal connections of knowledge and engineering application background (such as: comparison of accuracy and economy of different processing methods). (3) Organize collaborative research activities: case studies to analyze the processing route design of a typical part (such as engine connecting rod). Virtual simulation operation: Use CNC machining simulation software in the computer room for programming and simulated processing. Flipped classroom: In groups, we conduct research on processing methods and process routes for a process problem (such as how to control the processing deformation of thin-walled parts), and organize students to discuss and share the best solution. Project-based learning (PBL) [11]: Work as a team to complete a micro project from design to process planning of a "small product". (4) Guidance and guidance: Inspect and guide students during their activities to promote in-depth thinking. Participation and interaction in student activities: (1) Actively answer questions and participate in discussions. Collaborative learning: assume a role in a group, exchange ideas with peers, and complete tasks together. (2) Hands-on practice: Participate in simulation operations and experiments. (3) Display and expression: Report the results of group discussion or project results.

After-school online/offline expansion (migration application) teacher activities: (1) Release expansion tasks: assign comprehensive homework, small course design, and open questions. (2) Provide expansion resources: recommend relevant advanced manufacturing technology videos, industry reports, corporate cases, etc. (3) Organize online Q&A: conduct online Q&A at a fixed time to respond to personalized questions. (4) Evaluation and feedback: Correct assignments and project reports, and provide personalized feedback.

Based on the support of online teaching platforms, QQ/WeChat groups, video conferencing software and other technical platforms, student activities: (1) Complete consolidation and expansion assignments. (2) Carry out project deepening: continue to improve the project in class and write a report. (3) Knowledge sorting and reflection: draw mind maps and write learning logs. (4) Online communication and help-seeking: Continue to communicate with teachers and students in the forum to solve subsequent problems.

4.4 Multiple Teaching Evaluations

Combining the online and offline mixed teaching model and the training model that integrates theoretical teaching, experimental teaching and practical teaching, this course breaks the single-dimensional, score-based evaluation mechanism and adopts a diversified assessment method that combines process evaluation and summative evaluation. The assessment link is subdivided into four links: Online Learning Performance, Classroom Participation Degree, Project assignment outcomes and Final Examination. The assessment method is divided into online and offline tests, project plan design and results display, group activity (flipped classroom) participation level, course design, experiments and practical operations, final exam, etc., as shown in Figure 4. Utilize the online platform (Rain Classroom) to focus on the perception, collection, analysis and monitoring of dynamic data of teachers and students, establish a three-dimensional assessment and evaluation system of knowledge, skills and quality and evaluation of teaching effects, provide feedback on students' learning status and teaching effects, and optimize and improve teaching content and methods in a timely manner. Explore the establishment of a data-driven teaching monitoring platform, build a flexible and open mutual recognition mechanism for digital learning results, and form a fully quantitative and intelligent education and teaching evaluation system based on big data [3,10].

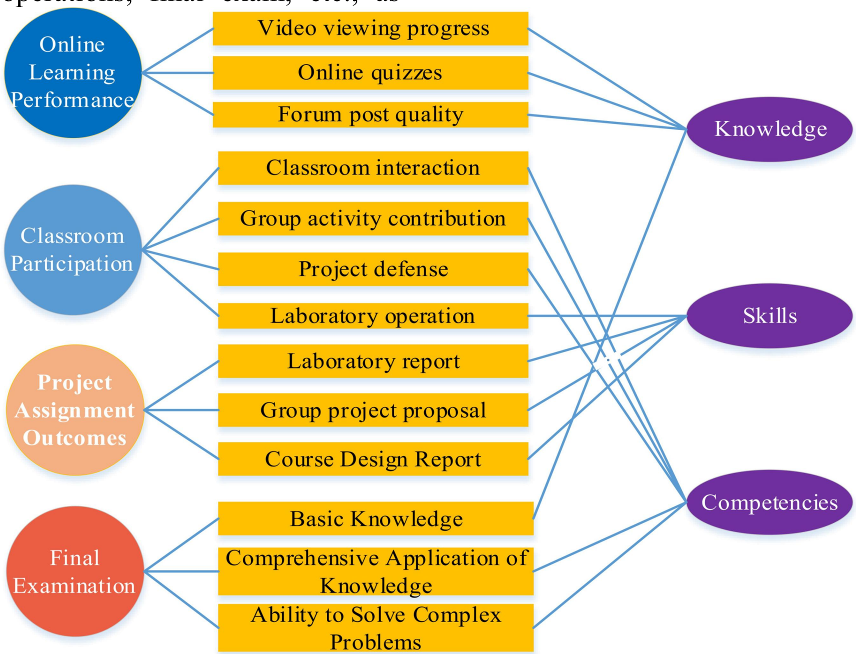

Figure 4. Assessment Methods and Teaching Effect Evaluation

5. Construction of Competency Map Based on OBE Theoretical Courses

The construction of curriculum Competency Map based on OBE theory follows the principle of "result-oriented, reverse design", takes the ultimate goal of the four-dimensional curriculum of "Knowledge-Analysis-Design/Comprehensive-Practice" as the starting point, sets the ultimate goal of the four-dimensional curriculum as a measurable and evaluable competency unit, and sets up primary, intermediate and advanced competency levels, as shown in Figure 5.

Under the teaching model that integrates theoretical teaching, experimental teaching and practical teaching, and combines online and offline blended teaching model, each specific ability unit is correspondingly matched with the course teaching content/tasks and supporting teaching activities, ensuring that each ability unit is specifically cultivated, as is illustrated in Figure 6. The assessment methods include classroom tests, assignments, project presentations, experimental reports, and practical operations. Considering the three-dimensional aspects of knowledge, skills, and qualities, the assessment methods corresponding to each ability unit are set up. This enables the evaluation of the learning situation and teaching effect of each ability unit, and guides professors to promptly optimize and improve the teaching content and methods, as shown in Figure 6.

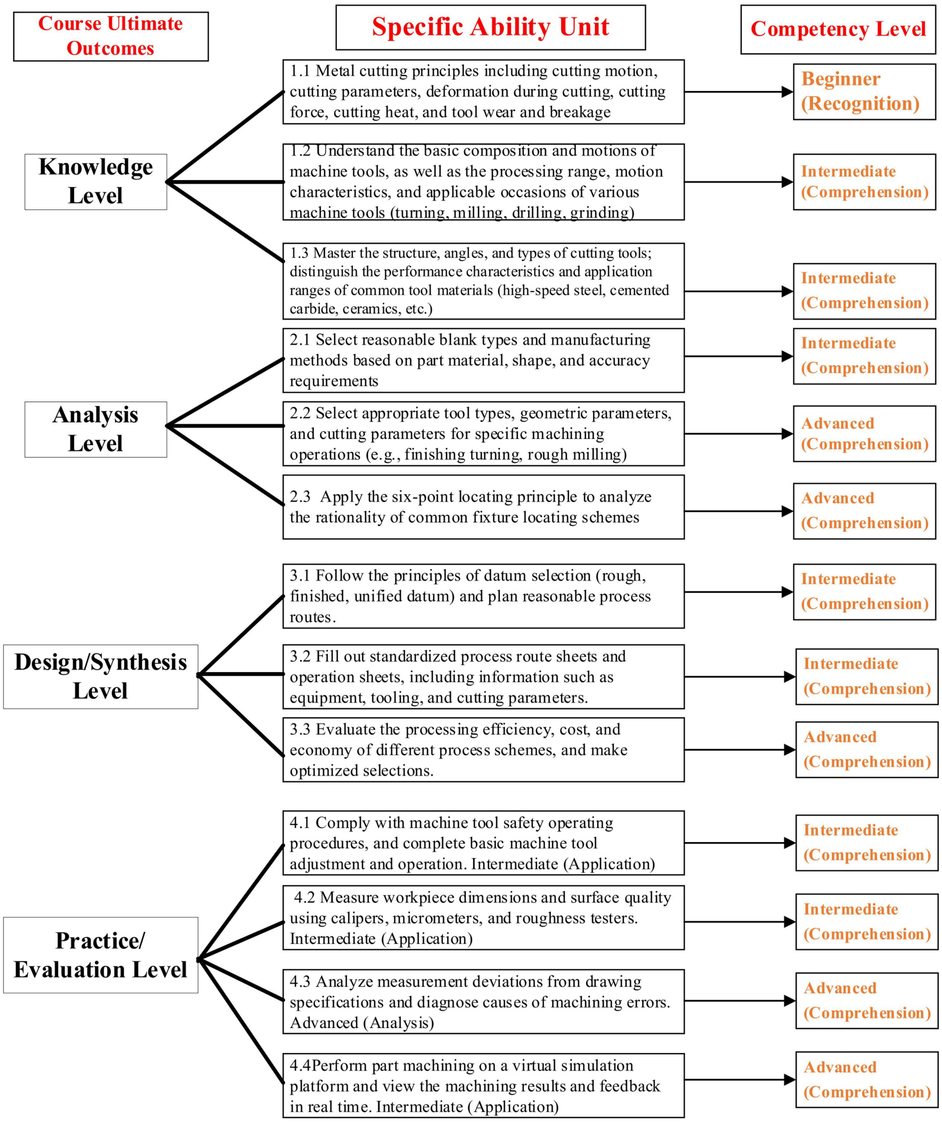

Figure 5. Construction of the Competency Unit of Fundamentals of Mechanical Manufacturing Technology

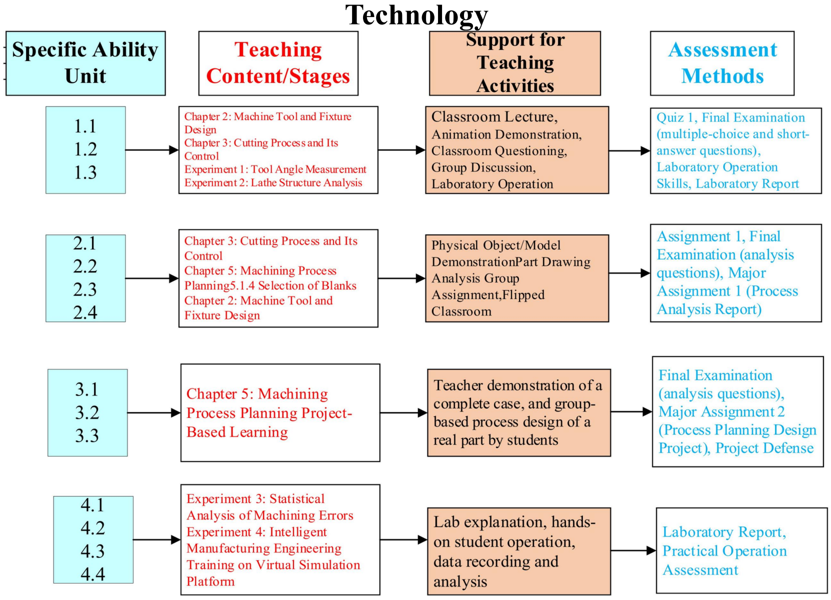

Figure 6. Course Teaching and Ability Mapping of Fundamentals of Mechanical Manufacturing Technology

6. Conclusion

The Competency Map of Fundamentals of Mechanical Manufacturing Technology constructed on the basis of OBE theory visualizes and routes the four-dimensional results of "Knowledge-Analysis-Design/Comprehensive-Practice", allowing students to clearly see their own ability shortcomings and progress trajectories, transforming from passive recipients to active constructors, effectively solving the stubborn problem of traditional courses that "Emphasize Knowledge Teaching and Neglect Ability Development", and realize the transformation of the education model from "Knowledge Input" to "Ability Output". "OBE theory + Competency Map" is a teaching paradigm that deeply integrates digital intelligence technology in the aspects of course objectives, course resource optimization, organizational model creation and teaching evaluation improvement. It not only provides a replicable and scalable practical path for cultivating high-quality compound talents who "Understand Theory, Can Analyze, Can Design, and Good at Practice" in the era of intelligent manufacturing, but also promotes profound changes in the education system and talent training model, and has important demonstration significance in improving the engineering literacy and innovative competitiveness of my country's mechanical professionals.

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