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Research on the Optimization of Mechanical Professional Curriculum System Based on the Cultivation of Engineering Design Ability—Take N Institute of Technology as an Example

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Abstract: *The essence of design is creative practical activities, and design ability is one of the key abilities of engineering innovation. How to implement engineering design ability as a graduation requirement into the engineering education curriculum system scientifically and systematically is a problem that must be solved in cultivating engineering talents suitable for the needs of The Times. On the basis of exploring the core connotation of engineering design ability, this study takes the mechanical major of N Institute of Technology as an example, specifically analyzes the current situation of the curriculum system requiring cultivating design ability for graduation, and puts forward optimization measures to provide reference and theoretical support for the reform of the curriculum system of cultivating engineering innovation ability.*

Keywords: *Engineering Design Ability; Mechanical Major; Curriculum System*

1. Introduction

In engineering education, design-oriented components such as course projects and capstone design projects have long been integral to cultivating students' engineering innovation capabilities. To foster entrepreneurial and innovative talent, the key lies in enhancing students' design competence. A critical challenge that every engineering discipline must confront is how to effectively integrate design ability as a graduation requirement into the curriculum. This study explores this issue in depth.

2. Connotation of Engineering Design Capability

Design is the cornerstone of creation and the core driver for the successful implementation of engineering projects. In recent years, more and more international well-known engineering education certification institutions and organizations have paid great attention to engineering design and engineering design education [1]. At its essence, design is a premeditated and creative activity. For instance, the Modern Chinese Dictionary defines "design" as:“Before formally doing a certain work, methods and patterns are formulated in advance according to certain purpose requirements.”[2] It can be seen that the work done also determines the object of design, such as mechanical, fashion, network design, or others. In the engineering certification standards for the 2019-2020 cycle revised by the US Discipline Accreditation Organization ABET (Accreditation Board for Engineering and Technology), engineering design is defined as: “Engineering design is a process of devising a system, component, or process to meet desired needs and specifications within constraints. It is an iterative, creative, decision-making process in which the basic sciences, mathematics, and engineering sciences are applied to convert resources into solutions. Engineering design involves identifying opportunities, developing requirements, performing analysis and synthesis, generating multiple solutions, evaluating solutions against requirements, considering risks, and making trade-offs, for the purpose of obtaining a high-quality solution under the given circumstances. For illustrative purposes only, examples of possible constraints include aesthetics, codes, constructability, cost, ergonomics, extensibility, functionality, interoperability, legal considerations, maintainability, manufacturability, marketability, policy, regulations, schedule, standards, sustainability, or usability.”[3].From this, it is evident that engineering design entails the pre-planning of blueprints, schematics, or methodologies to fulfill project specifications. Depending on the project type, it may manifest as mechanical, architectural, software, or other specialized design disciplines. Crucially, the design process must account for multifaceted constraints to deliver solutions that meet stipulated requirements.

In 2016, China officially joined the "Washington Agreement" of engineering education undergraduate professional certification, which needs to find a unique path matching the engineering power in the training mode of professional engineers [4]. In this context, the Chinese engineering education professional certification association (hereinafter referred to as the certification association) academic committee organization formulated the “Engineering Education Certification General Standard Interpretation and Use Guide”, and explain the standard item “Design or Develop Solution ability”, which means being able to design solutions for complex engineering problems, designing systems, units (components) or process flows that meet specific needs, and reflecting innovative thinking in the design process, considering social, health, safety, legal, cultural, and environmental factors[5].

Although there are slight differences in how "engineering design" is defined across countries, the cultivation of engineering design competency universally requires students to holistically consider real-world production and practical living conditions when developing blueprints, plans, and solutions. This involves conducting multi-factor, interdisciplinary analyses—grounded in market insights and user needs—while accounting for diverse stakeholders.As a professional competency, engineering design ability also encompasses comprehensive "soft skills," including:Humanistic literacy, Cross-cultural communication,Collaboration,Lifelong learning,International engagement and so on.

In summary, this study defines engineering design competency as the ability to develop preemptive solutions (e.g., technical drawings, schematics, or methodologies) for concrete problems under specified constraints, encompassing the following dimensions (see Figure 1):

1) Problem Identification Ability. The purpose of the plan is to solve the problem, which requires students to find the problem from the existing technical level. All the design activities come from the problem, only find and know the problem can be targeted to advance the plan.When students master the relevant knowledge of the subject, and have the ability of interdisciplinary thinking, empathy, research and collaboration, they can broaden the horizon of problems and identify problems in different situations.

2) Problem Expression Ability. Students are able to accurately express or elaborate on the problem, its causes, performance, consequences, and break down the problem into smaller parts in order to have a clearer understanding of its components and key factors. Students can fully mobilize the ability of divergent thinking, constantly consult information, listen to suggestions, etc., to improve their thinking from an interdisciplinary perspective.

3) Problem-solving Ability. After clearly thinking, students need to turn their thinking into solutions, plans or steps to solve the problem. This requires students to use inductive thinking deduction, logical reasoning and other thinking abilities to clarify their ideas, and then comprehensively use drawing, proposition, programming and other methods to solve problems. In this process, they can integrate the knowledge of different disciplines, and have good cooperation and communication with the team.

4) Ability to Choose Solutions. In the case of different stakeholders, environment, safety and other factors, students can consider the impact of engineering solutions in the world, economy, environment and society, realize the professional ethics responsibility in the engineering environment, and make wise choices.

Therefore, we can design a schematic diagram of the engineering design capability based on the problem orientation, as shown in Figure 1.

3. Analysis of Engineering Design Ability Based on Bloom's Educational Theory

As can be seen from Figure 1, the concept of "design capability" or "the ability to develop preliminary drawings and solutions" can be understood as a multi-layered competency structure comprising a series of subordinate abilities. According to Bloom's taxonomy of educational objectives, the core competence of engineering design ability was reconstructed from the three dimensions of cognitive, emotional and motor skills in this study (see Figure 2).

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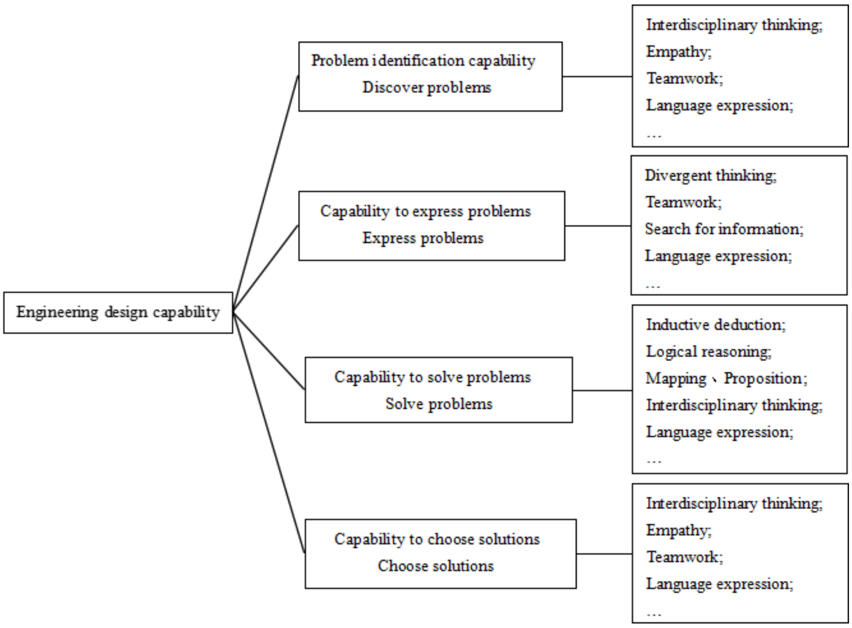

Figure 1 : Schematic diagram of problem oriented engineering design capability composition

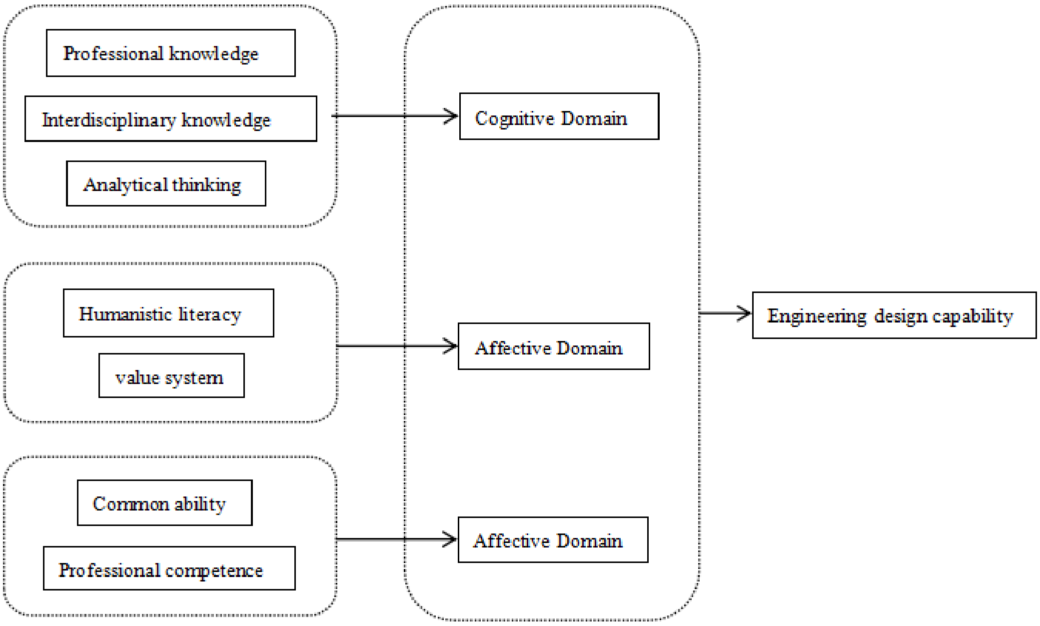

Figure 2 : Schematic diagram of core competencies in 3D engineering design

First of all, the cognitive field in the Bloom's taxonomy of educational objectives involves the development of knowledge, thinking and other aspects. First, knowledge is the basis of cultivating engineering design ability. Whether the discovery, expression and formulation of engineering problems, should be based on professional and interdisciplinary knowledge. Professional knowledge involves natural science knowledge, professional basic knowledge and instrumental basic knowledge. Interdisciplinary knowledge involves the humanities and social disciplines. Due to the background of the new technology and industry ,the engineering problems in real industry environment tend to be cross-cutting, comprehensive and challenging.Therefore,the cultivation of students' engineering design ability should keep pace with the times, to enable students to cope with the dynamic, complexity and uncertainty of the future industry development, break the boundaries of subject knowledge, and use professional knowledge and interdisciplinary knowledge in the process of dealing with practical problems, thus put forward the feasible and optimal solution. Second, analytical thinking is the core of engineering design ability. In the early stage of engineering design, it is necessary to use analytical thinking to conduct in-depth analysis of project requirements, restrictive conditions and technical feasibility, so as to provide accurate basis for the formulation of the design scheme. In the design process, we will constantly use analytical thinking to evaluate and optimize the design scheme to

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ensure that it meets the requirements. Analytic thinking ability requires students to grasp the method of analyzing problems, apply the tools of analyzing problems, use logical reasoning ability to properly solve problems, and finally choose logical, reasonable and rational solutions.

Secondly, the emotional domain refers to the development of value systems through education, encompassing the ability to organize, express, and apply these values in life and work, including humanistic qualities such as sense of responsibility and empathy, as well as values such as world outlook, outlook on life and outlook of science and technology ethics. Engineering talent is the successor of the national strategy and builders. Cultivating students' values is beneficial for them to clarify their responsibilities, learn to identify and handle difficulties in engineering practice, understand the relationship between engineering, technology, mission, responsibility, and possible value conflicts, judge the causes and potential value conflicts, and thus choose the best solution. Only fully establish a sense of social responsibility and mission, can fully understand the products' requirements, produce engineering design products that contribute to people's happiness and social progress.

Finally, the field of movement skills refers to the ability to perform behaviors related to the research field, including common abilities such as language expression and teamwork, as well as professional abilities such as mapping and software design. The design activities requires effective communication with team members, superiors and customers to ensure the smooth progress of the project. Cultivating students' ability of language expression and teamwork is conducive to close cooperation with team members, reduce misunderstanding and conflict, and improve the overall efficiency of the team.

In summary, the cultivation of engineering design competency requires not only the development of students' professional knowledge and technical skills, but also the nurturing of humanistic literacy and related qualities. From the perspective of curriculum, supporting engineering design ability requires general education courses such as humanities and social sciences and advanced mathematics, as well as basic professional courses, professional courses and practical links.

4. Current Situation and Optimization Measures of Mechanical Professional Curriculum System Based on the Cultivation of Engineering Design Ability —— Take N Institute of Technology as an Example

As an important content of the graduation requirements of engineering professional talent training, design ability must be implemented in several courses, and it can be reflected as the different support strength of strong, medium and weak support for the index points of design ability. N Institute of Technology founded in 2000 is a full-time undergraduate institution approved by the Ministry of Education of China. The college has 14 secondary colleges and 52 undergraduate majors, including 32 engineering majors, accounting for 61.5%.There are 6 mechanical majors, accounting for 18.75% of engineering majors. In this study, the curriculum system of N Institute of Technology supports the engineering design ability, further propose measures to optimize the curriculum system.

4.1 The Status Quo of the Mechanical Professional Curriculum System based on the Engineering Design Ability Training

The mechanical majors at N Institute of Technology include Mechanical Design and Manufacture and Its Automation, Mechatronic Engineering, Intelligent Manufacturing Engineering, Automobile Service Engineering, Automotive Engineering, New Energy Vehicle Engineering. Due to the huge amount of courses, in order to simplify the examples, table 1 only presents the courses that support the cultivation of design ability in the field of mechanical design, manufacturing, and automation. From table 1, it can be seen that the curriculum system of N Institute of Technology supporting engineering design ability includes general education courses, professional basic courses, specialized courses and practical links.

An analysis of how general education courses support engineering design competency across six majors reveals that two programs—Automotive Service Engineering and New Energy Vehicle Engineering—lack curricular alignment.Specifically, foundational courses such as Advanced Mathematics and College Physics fail to provide meaningful support for developing design capabilities in these disciplines.

From the perspective of the support of professional engineering design ability in specialized courses, there are generally more than two design courses. For example, Mechanical Design, Manufacturing and Automation major has three courses: Virtual Design of Mechanical Products, Mold Design and

Manufacturing, Digital Design and Manufacturing Technology. And the Mechatronic Engineering major has the course of embedded system design, the Intelligent Manufacturing Engineering major has two courses: Intelligent Product Design and Development and Intelligent Factory Planning and Design.

Table 1: Overview of the design ability course system of supporting Mechanical majors of the N Institute of Technology(Taking Mechanical Design and Manufacture and Its Automation as an example)

<table>
<tr><th rowspan="2">Specialty Curriculum</th><th colspan="2">General Education Courses</th><th colspan="2">Professional Basic Courses</th><th colspan="2">Specialized Courses</th><th rowspan="2">Practice Links</th></tr>
<tr><th>Obligatory Courses</th><th>Elective Courses</th><th>Obligatory Courses</th><th>Elective Courses</th><th>Obligatory Courses</th><th>Elective Courses</th></tr>
<tr><td rowspan="9">Mechanical Design and Manufacture and Its Automation</td><td>Thought and Morality and the Rule of Law (H)</td><td rowspan="9">Aesthetic Education Courses (M)</td><td>Rational Mechanics (M)</td><td>Power Drag Automatic Control System A(L)</td><td>Mechanical Manufacturing Technology (H)</td><td>Automatic Manufacturing System (M)</td><td>Survey and Draw A(M)</td></tr>
<tr><td>Outline of Modern Chinese History (M)</td><td>Mechanics of Materials (M)</td><td>Python Language Foundation and Applications (H)</td><td>Electrical Control and Plc Applications C (H)</td><td>Mechanical Product Virtual Design (H)</td><td>Mechanical Design Course Design (H)</td></tr>
<tr><td>An Introduction to Mao Zedong Thought and the theoretical System of Socialism with Chinese Characteristics (L)</td><td>Engineering Graphics A(M)</td><td rowspan="7">Material Corrosion and Protection (M)</td><td>Mechanical Innovation Design (H)</td><td>Mold Design and Manufacture (H)</td><td>Electrical and Electronic Practice B (H)</td></tr>
<tr><td>Higher Mathematics A(M)</td><td>Principle of Machinery (M)</td><td>Mechanical Manufacturing Equipment Design (H)</td><td>Equipment Fault Diagnosis Technology (H)</td><td>Course Design of Mechanical Manufacturing Technology (H)</td></tr>
<tr><td rowspan="5">College Aesthetic Education (M)</td><td>Machine Design (H)</td><td>3D Printing Molding Process and Materials (H)</td><td>Intelligent Manufacturing Technology (H)</td><td>Fieldwork (M)</td></tr>
<tr><td>Electroelectronics Experiments (M)</td><td rowspan="4">Numerical Control Principles and Programming Techniques (H)</td><td>Precision and Special Machining (H)</td><td>Computer-Aided Design Skills Training (H)</td></tr>
<tr><td>Hydraulic and Pneumatic Transmission Technology A (H)</td><td>3D Printing Data Modeling and Processing (H)</td><td>Professional Skills Training (H)</td></tr>
<tr><td rowspan="2">Engineering Software Application (M)</td><td rowspan="2">Digital Design and Manufacturing Technology (H)</td><td>Graduation Field Work (M)</td></tr>
<tr><td>Graduation Project (thesis) (H)</td></tr>
</table>

Note: The strong strength of the course's support for the graduation requirements of the design ability is expressed by H (high), M (middle) and L (weak) respectively

From the perspective of the support of the professional engineering design ability in the practical links, the six mechanical majors all attach importance to the development of the practice link. For example, the practical aspect of supporting engineering design ability cultivation in the major of Mechanical Design and Automation accounts for 22.5% of the entire curriculum system, Mechanical and electronic engineering accounts for 37.9%, while vehicle engineering accounts for 55%.

From the perspective of the support of compulsory and elective course for engineering design ability, the six mechanical majors have set up a large number of professional elective courses. Especially in the field of automotive service engineering, only three compulsory courses support the cultivation of design ability. However, excessive elective courses are difficult to cultivate engineering design ability for all students.

From digital technology for mechanical engineering design ability course, only the Mechanical Design Engineering and Automation major has two courses, CNC Principles and Programming Technology, 3D Printing Forming Technology and Materials, which support the cultivation of engineering design ability. And the Intelligent Manufacturing Engineering major supports the cultivation of engineering design skills through two courses: Numerical Control Principles and Programming Technology, and Digital Design and Manufacturing Technology. The other four professional have no digital technology for engineering design ability support course.

Through an analysis of the curriculum systems supporting engineering design capabilities across six mechanical engineering-related majors at N Institute of Technology, it can be observed that these programs typically offer more than two design-focused courses, with a significant proportion of practical training courses. However, there are also shortcomings such as neglecting general education courses, obvious deficiencies in courses that use digital technology for engineering design capabilities, and difficulty in covering all students with engineering design capabilities supported by a large number of elective courses in professional courses.

4.2 Measures for Optimizing the Curriculum System based on the Cultivation of Engineering Design Capabilities

4.2.1 Refine the Graduation Requirements of the Talent Training Program

Engineering design ability belongs to the content of the engineering certification graduation requirements 3. Its basic content is to be able to design solutions for complex engineering problems in the fields of construction machinery, intelligent engineering machinery, and intelligent manufacturing,with the ability to design mechanisms, components, mechanical systems, and process flows that meet engineering needs, and demonstrate innovative thinking in the design process, considering social, health, safety, legal, cultural, and environmental factors. It includes three aspects: first, it can design solutions for the problems in the field of professional engineering; second, it has the ability to meet the engineering design; third, it can reflect the innovation consciousness and comprehensively consider various factors in the engineering design.

Graduation requirements determine the construction of the curriculum system. Detailed graduation requirements can not only ensure that each course can support the achievement of the graduation requirement of cultivating design ability, but also encourage teachers to consciously cultivate students' design ability in classroom teaching, thereby better evaluating students' learning outcomes and ensuring that students achieve expected learning goals.

4.2.2 Determine the Supporting Courses according to the Graduation Requirements

Each graduation requirement for engineering certification is based on the achievement of several course objectives that support this graduation requirement. Each graduation requirement can be further subdivided into several observation points, for example, graduation requirement 3 can be subdivided into three observation points: 3.1, 3.2, 3.3, etc. Each observation point can be supported by several courses, so as to implement the cultivation of engineering design ability. For instance, observation point 3.3 mainly reflects innovative consciousness and comprehensive consideration of various factors in engineering design, which should be supported by the general education courses and comprehensive curriculum objectives, so as to avoid the problem of general education courses not supporting engineering design ability in some majors. At the same time, the achievement of graduation requirements should be open to all graduates, a course can only serve as a support for graduation requirements if it is studied for all students. Therefore, elective courses cannot guarantee learning for all students in this major, and cannot be used as courses to support graduation requirements, in order to avoid situations where elective courses support graduation requirements in all six majors.

4.2.3 Strengthen the Rationality Evaluation of the Curriculum System

Reasonably designing a curriculum system is one of the important means to achieve graduation requirements. The rational evaluation of curriculum system can promote the curriculum reform and continuous improvement, and timely meet the needs of education modernization. First, the talent development plan must be revised based on talent demand research, and the reasonable evaluation of talent development goals must be conducted through employers, industry experts, and graduates, experts from industry departments and graduates. Second, reasonably evaluate the curriculum system. Under the current technological background of big data, artificial intelligence, Internet of Things, intelligent manufacturing, etc, only by timely analyzing which existing curriculum systems are outdated and which need to keep up with the times, and adding corresponding courses to adapt to the requirements of the artificial intelligence era for enterprise intelligent transformation, can we avoid the lack of courses related to data technology and artificial intelligence to support the cultivation of engineering design capabilities.

4.2.4 Timely and Scientific Revision of the Course Syllabus

The cultivation of engineering design ability is reflected in the realization of the curriculum objectives supported by it, and the key to the achievement of the curriculum objectives lies in the realization of the curriculum objectives step by step in classroom teaching. Course objectives support graduation requirements, and graduation requirements support the realization of talent training goals. Therefore, while revising the talent training program, the course objectives must adapt to the new graduation requirements and observation points, and the course syllabus must also be adjusted according to the latest version of the talent training program. On the one hand, this can avoid situations where graduation requirements are not supported by corresponding courses; on the other hand, we can

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focus on the course objectives, select course content that meets the practical needs of production or service, timely introduce interdisciplinary courses such as artificial intelligence and digital twins, and offer practical content with strong design, research, and comprehensive aspects. This will enable students to master the technical means and experimental methods required for engineering design in a real work environment, cultivate their hands-on ability, application ability, thinking ability, and innovation ability.

4.2.5 Multiple Evaluation based on Engineering Design Connotation

The implementation of graduation requirements cannot be separated from a reasonable evaluation method. As a high-level ability, the evaluation of engineering design ability needs to use methods that are applicable to it. Firstly, engineering design is not only the process of technology application, but also the embodiment of innovative thinking. Therefore, the evaluation of students' engineering design ability should pay attention to the development of thinking. In evaluating the development of students' thinking abilities, attention should be paid to whether students can analyze problems from multiple perspectives, propose innovative solutions, and demonstrate creativity and critical thinking skills in the design process. This can be examined through design competitions, innovative projects, case studies, and other means. Secondly, engineering design often involves interdisciplinary collaboration and teamwork. Therefore, the evaluation of engineering design ability should focus on performance evaluation, paying attention to students' performance in team projects, including communication and coordination skills, teamwork spirit, and leadership ability. This can be comprehensively evaluated through team project reports, peer evaluations, mentor feedback, and other methods. Thirdly, the ability to solve practical engineering problems is the core manifestation of engineering design capability. This can be achieved by focusing on whether students can apply their learned knowledge to analyze, design, experiment, and verify in practical courses such as course design, graduation project, and internship training, and ultimately propose feasible solutions, thereby examining students' ability to solve practical engineering problems.

5. Conclusion

The primary issue in accelerating technological innovation is to cultivate talents with innovative capabilities, and the cultivation of talents with innovative design capabilities cannot be separated from engineering education reform and innovation oriented towards major national strategies and needs.On the basis of exploring the connotation of engineering design, this study concludes that design ability is a graduation requirement supported by multiple course objectives and relies on the internal logic of achieving multiple course objectives. Based on the core competency of engineering design ability, taking the mechanical major of N Institute of Technology as an example, this paper explores the current situation of the curriculum system based on the cultivation of engineering design ability, and proposes countermeasures to optimize the curriculum system from reverse design and forward construction.

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