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Breakthrough and Reconstruction: Cultivation and Practice of Innovative Abilities for Excellent Mechanical Engineering Talents

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ABSTRACT: At present, the engineering education system generally faces problems such as the disconnection between talent cultivation and enterprise needs, insufficient connection between the curriculum system and engineering practice, and vague paths for cultivating students' innovative abilities. These issues make it difficult for high-quality mechanical engineering talents to meet the requirements of emerging engineering education development. This paper reconstructs an open, interdisciplinary, and modular curriculum system that emphasizes the cultivation of innovative and practical abilities, and establishes a mechanical talent cultivation model featuring practicing in knowledge acquisition, learning in practice, and integrating knowledge with practice. It further unblocks the implementation paths for multidisciplinary collaborative integration in mechanical engineering, the inter-embedding of theoretical teaching and practical teaching, and the interactive discussion mechanism for mutual improvement between teachers and students. Meanwhile, a progressive and multilevel practical teaching system (covering basic experiments, advanced experiments, comprehensive training, and innovative practical projects) is built to effectively connect the capability transformation channel from theoretical cognition to engineering practice, thereby enhancing students' higher-order thinking and practical innovation abilities. This research will improve the adaptability of talent cultivation to national strategic needs and enterprise technological innovation demands, and provide solid talent support for building a powerful education country.

Keywords: High-quality mechanical talents, Curriculum system, Teaching model, Cultivation path, Practical teaching system, Innovative ability.

1. INTRODUCTION

From the perspective of the Emerging Engineering Education (EEE) initiative, engineering education is exhibiting unprecedented characteristics of transformation, interdisciplinarity, integration, and openness, and the cultivation of students' innovation competence has become a central concern in engineering education both in China and internationally. One of the most prominent challenges in the current transformation of mechanical engineering education is that, against the background of rapidly evolving knowledge, the disconnect between talent cultivation and enterprise needs, insufficient alignment between the curriculum system and engineering practice, and unclear models and pathways for cultivating innovation competence have become increasingly evident. These problems directly cause traditional engineering education to deviate from the EEE goals of interdisciplinary integration, innovation in talent-cultivation models, and competency-oriented education, making it difficult to develop high-caliber engineering talent who can solve complex engineering problems, demonstrate interdisciplinary collaboration competence, and sustain lifelong learning and innovation [1, 2].

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Currently, Mechanical Engineering Majors are an important component of engineering education and exhibit the following notable characteristics. (1) Broad institutional coverage: mechanical engineering programs are widely distributed across the higher education system and include institutions of different types and levels. (2) A large student population: Due to the large number of enrolled students, it is difficult to realize personalized training in the cultivation process. Meanwhile, as the job demands are highly diversified, the employment guidance cannot be precisely controlled and implemented effectively. (3) High curriculum difficulty: mechanical engineering programs involve many teaching hours and broad course content, with a relatively large proportion of abstract and complex theoretical knowledge. This places greater demands on students' ability to understand and apply disciplinary knowledge and increases learning difficulty. (4) Limited conditions for practice-based learning: practice-based teaching is constrained by time, space, and available resources, making it difficult to fully realize the practical Instruction intended role and weakening the transformation of students' theoretical knowledge into practical competence [3-5]. Mechanical engineering talent cultivation also faces a substantial gap between the intended development of students' engineering foundations, practical competence, and innovation competence and the limitations of traditional cultivation models, systems, and pathways. It is therefore urgent to overcome the constraints imposed by limited temporal and spatial resources, curriculum contact hour quota, and large-scale education models, and to address bottlenecks that restrict the development of students' innovation competence [6].

Master Plan for Building China into a Leading Country in Education (2024–2035) calls for strengthening students' practical competence, complex problem-solving ability, and innovation capability [7]. For mechanical engineering programs, these requirements need to be implemented through both curriculum content and practical teaching. The curriculum should emphasize the connections among knowledge in mechanical design, manufacturing, and control, while practical tasks should provide students with opportunities to apply theoretical knowledge, analyze problems, and validate proposed solutions. At the same time, tasks should be arranged according to students' knowledge foundations at different stages of learning, with clear requirements for faculty guidance and student outcomes, so that the training objectives are aligned with teaching activities.

The cultivation of mechanical engineering talent needs to take into account professional knowledge, engineering practice, sense of responsibility, and lifelong learning ability [8-10]. This study focuses on the connection between course learning and engineering practice, as well as the articulation of practical tasks across different stages of learning. To address these issues, reform approaches are proposed from three aspects: training objectives, curriculum system, and teaching organization, with teaching activities arranged through experiments, competitions, research, and enterprise-based practice. On this basis, a UAV project is used to illustrate how practical tasks can be organized throughout the four-year undergraduate program, providing a reference for related teaching reforms in mechanical engineering programs.

Project-based learning, CDIO engineering education, and work-integrated learning provide references for engineering talent cultivation at different levels. Project-based learning organizes learning around project tasks and emphasizes the integrated application of knowledge through practice [11]. CDIO integrates the learning of professional knowledge with the development of engineering competence through an integrated curriculum and design–implement activities [12]. Work-integrated learning, in turn, emphasizes the connection between course learning and workplace practice and designs forms of student participation according to their prior knowledge and learning objectives [13]. Drawing on the characteristics of mechanical engineering programs, this study applies these educational approaches in terms of curriculum organization, practical tasks, and academic-year arrangements, with the relevant comparisons presented in Table **1**.

The teaching models discussed above and the framework proposed in this study share a common emphasis on practice-based learning, knowledge application, and engagement with engineering tasks. The primary contribution of this study lies in the contextualized organization and implementation of these pedagogical approaches within the curriculum structure and developmental stages of mechanical engineering education. At the curriculum level, modular course design is adopted to strengthen the integration of core mechanical engineering knowledge with interdisciplinary content. At the practical level, a range of learning activities is provided through foundational experiments, comprehensive training, research activities, and enterprise-based tasks. By academic year, a UAV project is used to illustrate the progressive relationships among structural modeling, manufacturing and control, system

Table 1: Comparison of Relevant Engineering Education Models and the Training Scheme Proposed in This Study

Educational Model	Main Organizational Form	Main Learning Content	Innovation in This Study
Project-Based Learning (PBL) [11]	Organizes knowledge learning and practical activities around project tasks	Knowledge application, problem solving, and collaborative learning	Engineering tasks with clearly differentiated disciplinary characteristics are embedded in both theoretical courses and practical teaching
CDIO Engineering Education [12]	Organizes teaching through an integrated curriculum and design–implement activities	Professional knowledge, individual and interpersonal skills, and product and system development capabilities	Mechanical design, manufacturing, and control knowledge are integrated, with modular and comprehensive experiments supporting systematic engineering practice
Work-Integrated Learning [13]	Purposefully integrates course learning with workplace practice through institutional–enterprise collaboration	Professional and workplace-related knowledge and skills	Authentic industrial projects and enterprise-based mentoring are introduced, with project tasks incorporated into practical teaching activities
Proposed Training Scheme	Integrates course learning, modular innovation experiments, competitions, research training, and enterprise-based projects	Mechanical engineering knowledge integration and project-oriented practical design	A four-year progressive framework is established, including foundational experiments, competition-based training, comprehensive innovation, research practice, and enterprise-based projects, together with cross-disciplinary project tasks

integration, and collaborative tasks. Accordingly, the distinctive feature of this study lies in its concrete implementation framework for undergraduate mechanical engineering education. However, the educational effectiveness of the proposed approach requires further validation through evidence derived from student work, process records, and competency assessment data.

2. REFORM OF THE TALENT CULTIVATION MODEL

The cultivation model for high-caliber mechanical engineering talent should center on developing students' higher-order thinking and require comprehensive and systematic reform from cultivation philosophy and objectives to implementation pathways. In terms of educational philosophy, we are moving beyond the traditional approach centered on subject knowledge toward a competency-based approach. Logical reasoning, critical thinking, engineering knowledge integration, and innovation-oriented knowledge-construction competence should serve as foundations for developing the core competencies of mechanical engineering talent. The cultivation model therefore focuses on reshaping cultivation philosophies and objectives, reconstructing the curriculum system, innovating teaching models, and establishing a practice-based education system, thereby forming a pathway for cultivating the innovation competence of high-caliber mechanical engineering talent.

Experiential learning theory provides a theoretical basis for integrating theoretical instruction with practical teaching. Kolb conceptualized learning as a process through which knowledge is created through the transformation of experience, emphasizing the interrelationship among concrete experience, reflective observation, abstract conceptualization, and active experimentation [14]. From this perspective, practical teaching in mechanical engineering should not only provide opportunities for hands-on operation and experimentation but also guide students to analyze results, connect practical experience with theoretical knowledge, and verify newly developed understanding. The approach proposed in this study, which emphasizes the integration of knowledge and practice, is consistent with this perspective. For example, in tool-related instruction, theoretical explanations of tool angles can be integrated with measurement and fabrication tasks, guiding students to analyze design differences based on observation and testing results and then apply relevant knowledge to refine their designs. By incorporating discussion, explanation, and repeated verification into practical activities, operational experience and theoretical understanding can reinforce one another.

With respect to curriculum and project organization, the CDIO engineering education framework provides an additional point of reference. Its standards emphasize mutual reinforcement among disciplinary courses, the integration of professional knowledge with the development of personal, interpersonal, and engineering system development capabilities, and the progressive arrangement of design–implement activities of increasing complexity [12]. This study relates these principles to the curriculum and practical training structure of mechanical

engineering programs. Modular courses are used to strengthen the connections among mechanical design, manufacturing, and control, while a four-year UAV project is employed to illustrate the organization of stage-specific tasks. Students progress from basic structural modeling to manufacturing, control, and system integration tasks, applying the knowledge and outcomes developed in earlier stages to subsequent learning activities. Experiential learning theory mainly explains the learning process within practical activities, whereas the CDIO framework provides guidance for curriculum articulation and the sequencing of engineering tasks. Together, they help clarify the organizational basis of the training scheme proposed in this study.

2.1. Reconstructing Talent Development Objectives

As higher education enters a phase of widespread access characterized by diversity, the reshaping of cultivation objectives should be grounded in trends of industrial transformation, follow fundamental educational principles, and align with students' individual development needs, thereby establishing an objective system that is tiered and categorized, dynamically adaptive, competency-oriented, and value-guided. In response to national development strategies and enterprise talent needs, cultivation objectives should be precisely defined by level and category, while ideological and political education should be strengthened to build a solid value foundation for students. At the same time, students' intrinsic motivation should be stimulated to achieve deep integration between value guidance and competency development. In this way, talent development objectives can meet the needs of the times while promoting students' all-round development and clarifying the core direction of talent cultivation.

Cultivating the innovation competence of high-caliber mechanical engineering talent requires renewal of the cultivation philosophy. In response to differentiated cultivation objectives, diversified cultivation programs and individualized cultivation pathways should be established, promoting a fundamental shift in talent development models from the traditional approach centered on disciplinary knowledge to a "competency-oriented" approach. Logical reasoning, critical analysis, engineering knowledge integration, and innovation-oriented knowledge-construction competence should serve as foundations for developing core competencies. A competency-oriented cultivation philosophy should be embedded throughout practice-based learning so that theory and practice reinforce each other and become deeply integrated, thereby comprehensively enhancing the innovation competence of mechanical engineering talent.

In this study, the innovation competence of mechanical engineering students is defined as the ability to identify and analyze problems in engineering tasks, integrate knowledge from mechanical engineering and related disciplines to develop solutions, evaluate those solutions through design, fabrication, and testing, and make further improvements based on the results. Its assessment should be task-specific and should focus on four dimensions: problem analysis, solution design, practical validation, and reflective improvement. The novelty of a proposed solution should be judged in relation to students' prior knowledge and the requirements of the task, while its feasibility and the evidence supporting its validation should also be considered.

To ensure that the training objectives are effectively reflected in teaching assessment, this study proposes the assessment indicators presented in Table **2**. The assessment evidence may include design reports, models or physical prototypes, experimental records, test reports, and revision records. The same assessment dimensions can be applied across different stages of learning, while the specific requirements should be adjusted according to the complexity of the tasks and the degree of students' independent completion.

The above indicators can be applied to tasks such as course projects, comprehensive experiments, and capstone projects. Assessment should consider both the final outcomes and the process through which they are developed. For team-based projects, students' individual design records, task completion, and performance during presentations or defenses should also be considered to determine their actual contributions. The basic, progressive, and higher-level performance descriptors are intended to distinguish different levels of achievement within the same assessment dimension and do not correspond directly to a specific academic year.

2.2. Reconstruction of the Curriculum System

Restructuring the knowledge system within a framework for cultivating outstanding engineering talent, it is necessary to strengthen the systematic connections among courses. In the lower years, emphasis should be placed on structured curriculum development centered on the curriculum structure and the Chinese "Two Features and One Degree" (Advanced, Innovative,

Table 2: Assessment Dimensions and Performance Requirements for the Innovation Competence of Mechanical Engineering Students

Assessment Dimension	Main Assessment Content	Basic Performance	Progressive Performance	Higher-Level Performance	Assessment Evidence
Problem Analysis	Ability to identify engineering problems and their constraints	Describes task requirements under instructor guidance	Independently identifies the main problem and analyzes relevant conditions	Identifies key problems based on available information or test results and explains the basis for the analysis	Problem analysis reports, requirement descriptions, and discussion records
Solution Design	Ability to propose and reasonably select solutions	Develops a basic solution by referring to existing methods	Proposes different solutions and compares their feasibility	Proposes solutions with potential for improvement in response to key problems and explains the reasons for selection and applicable conditions	Design descriptions, solution comparisons, models, or drawings
Practical Validation	Ability to validate solutions through fabrication and testing	Completes operations and tests according to prescribed procedures	Selects testing methods according to the objectives and analyzes the results	Designs an appropriate validation process, explains differences between the results and expectations, and analyzes sources of error	Physical products, experimental records, and test reports
Improvement and Optimization	Ability to revise solutions based on evidence	Identifies deficiencies and makes revisions under instructor guidance	Proposes improvement measures based on test results	Compares performance before and after improvement, explains the effectiveness of the improvements, and identifies remaining limitations	Design versions, revision records, and comparative results

Challenging) standard for course construction. By consolidating the knowledge framework, students' competence in integrating and constructing knowledge can be developed, enabling systematic construction from individual concepts to an interconnected knowledge network. In the upper years, the curriculum should gradually shift toward less-structured course design using open-ended and interdisciplinary research-oriented or engineering-oriented projects as the main vehicles. By breaking disciplinary boundaries, theoretical knowledge can be transformed into practical innovation, promoting students' progressive development from knowledge integration and construction to knowledge transfer and creation. This forms a curriculum system in which innovation and entrepreneurship education is integrated with disciplinary education and theoretical education is mutually embedded with practice-based education.

The curriculum system for mechanical engineering programs requires transformation and upgrading, with stronger general education foundations and a competency-oriented knowledge system. First, value guidance should be strengthened as a core element of the knowledge system, with emphasis on values such as patriotism and independent innovation. Second, core disciplinary knowledge should be strengthened. Knowledge-graph systems should be used to organize key disciplinary concepts, strengthen curriculum integration, emphasize higher-order learning, innovativeness, and an appropriate level of challenge in course content, and standardize syllabi [15]. Competency maps should be used to construct the curriculum system, refine core courses, and enhance the depth and breadth of the curriculum. Third, cutting-edge scientific and technological knowledge. It should be strengthened by incorporating recent advances from academic research and technological development into courses and updating teaching content in a timely manner. Fourth, interdisciplinary knowledge should be strengthened. Disciplinary barriers should be reduced, interdisciplinary knowledge integration should be promoted, and the knowledge system should be renewed to form a curriculum characterized by integration across mechanical engineering and related fields, thereby supporting the solution of complex engineering problems. Interdisciplinary project-based courses should integrate knowledge modules from mechanical engineering, information science, materials science, and related fields to form dynamically updated course clusters [16]. At the same time, core course content should be systematically organized and integrated with cutting-edge topics such as intelligent manufacturing and green design to ensure the contemporaneity and practical relevance of the knowledge system. Fifth, strengthen knowledge of artificial intelligence. Establish general and specialized courses on artificial intelligence to provide a framework for interactive teaching between teachers and students in the classroom, a platform for personalized student development, and opportunities for independent learning [17]. Sixth, practical training components. Practice-based teaching should be strengthened by increasing its proportion in the cultivation plan, reinforcing training

through challenge projects, and optimizing the project-based curriculum system.

Digital and intelligent technologies provide a driving force for the reform of the curriculum system, with knowledge graphs serving as a major vehicle for digital transformation and intelligent educational support. They enable structured knowledge representation in the curriculum system, precise alignment with learner needs, and personalized planning of learning paths, upgrading the curriculum from a static framework guided by experience to a data-driven dynamic system. They also support precise analysis of the logical structure and paths for developing competencies of core courses and practice-based learning components, reconstruction of the structure of the knowledge system architecture based on engineering systems thinking, reduction of barriers across disciplinary and professional knowledge, and stronger alignment between the curriculum and enterprise needs. Through modular curriculum design, each student can be provided with an individualized development pathway.

2.3. Innovation in Teaching Models

The key nodes in the pathway for cultivating the innovation competence of high-caliber mechanical engineering talent are reconstruction of the curriculum knowledge system, innovation in classroom teaching models, and reform of the practice-based education system. These nodes establish pathways for coordinated interdisciplinary integration between mechanical engineering and other fields, the mutual embedding of theoretical and practice-based teaching, and interactive seminars for instructors and students that promote reciprocal learning. Mechanical engineering should promote integration and coordinated sequencing across fields such as information science and materials science. Theoretical courses, practice-based courses, comprehensive training courses, and frontier-oriented courses should be optimized and reorganized, with theoretical and practice-based teaching appropriately interwoven to promote innovation in talent development models. A new teaching paradigm should be constructed through competency maps, strengthening the complete teaching sequence of pre-class independent inquiry, in-class interactive seminars, and after-class practical application, and creating an interactive atmosphere for collaborative teacher-student discussion. Through two-way faculty engagement, reform of teaching evaluation, guidance-oriented incentive mechanisms, and pedagogical approaches such as problem-oriented learning, project-based learning, flipped classrooms, and seminar-based instruction, interaction between instructors and students and joint participation in educational reform can be strengthened [18, 19]. Students' ability to formulate and synthesize problems should be progressively improved, while traditional mechanical engineering courses should be deeply integrated with enabling technologies such as Internet Plus, artificial intelligence, industrial big data and cloud computing, and digital twins. This can shift teaching from traditional one-way instruction from teachers to students toward collaborative interaction among teachers, students, and technology, while shifting students from passive learning to active exploration. Greater emphasis should be placed on higher-order thinking and practical innovation competence, while individualized learning and lifelong learning should become important modes of talent cultivation.

In view of the characteristics of mechanical engineering programs, a talent development model of practising through knowing, seeking knowledge through action, and integrating knowledge and action should be promoted. Practice-based components should be introduced into theoretical courses. For example, theoretical instruction on basic cutting-tool angles can be combined with cutting-tool testing and verification, cutting-tool fabrication, and innovative cutting-tool angle design, so that hands-on activities strengthen students' understanding of theoretical knowledge and stimulate innovation. During practice-based teaching, hands-on operation, practical training, and authentic engineering practice should be integrated with relevant theoretical knowledge. Authentic industry projects and cutting-edge technologies should be introduced, and project-based learning should be used to implement instructional design tasks. Students can be organized into learning groups at different levels, with differentiated organization and guidance designed according to the characteristics of each group. Particular emphasis should be placed on learning by doing and integrating theory with practice. This approach strengthens students' critical thinking, logical reasoning, and creativity; guides them to apply multidisciplinary knowledge to solve complex engineering problems; strengthens hands-on competence; stimulates innovative initiative; and promotes the shift from knowledge transmission to the development of innovation competence.

3. REFORM OF PRACTICE-BASED TEACHING

Against the background of the manufacturing sector's transformation toward high-end, intelligent, and green development, the innovation competence of high-caliber mechanical engineering talent has become a core driving

force for industry development. Traditional practice-based teaching models can no longer meet contemporary talent development needs and therefore require systematic reform across multiple dimensions. Measures including optimizing verification experiments, strengthening challenge- and competition-based training, developing digital and intelligent platforms, conducting modular and comprehensive innovation experiments, deepening research and innovation training, and advancing industry-education integration provide key avenues for reforming practice-based teaching while developing students' competence in solving complex mechanical engineering problems.

3.1. Strengthening the Foundation: Optimizing the Construction of Verification Experiments

Verification experiments are a fundamental component of practice-based teaching. They help students confirm theoretical principles and deepen their understanding of concepts in general and disciplinary education. In mechanical engineering practical education, traditional verification experiments often suffer from outdated content and overly limited formats. To meet contemporary talent development needs, these experiments should be systematically optimized. Based on the core elements supporting students' experimental competence and the corresponding indicators in the competency matrix, a structured system of laboratory courses, experimental projects, and experimental platforms should be established. On the one hand, laboratory equipment and projects should be updated by introducing advanced mechanical design methods, manufacturing processes, and control technologies, allowing students to engage with cutting-edge knowledge and skills. On the other hand, greater emphasis should be placed on inquiry and guided exploration by embedding guiding questions throughout the experimental process to encourage students to think critically, identify problems, and analyze problems, thereby laying a solid foundation for practical competence [18-20]. For example, in verification experiments for the Mechanical Principles course, students should not only verify the basic principles of mechanism motion but also be guided to consider how mechanism performance can be improved, thereby fostering the early development of innovative thinking.

3.2. Stimulating Potential: Strengthening Challenge- and Competition-Based Training

Challenge- and competition-based training is an effective way to stimulate students' innovative potential. By participating in mechanical engineering innovation competitions, such as National College Mechanical Innovation Competition and National Undergraduate Engineering Training Integration Ability Competition, students can acquire interdisciplinary knowledge and emerging technologies in authentic competitive settings, apply what they have learned to practical problem solving, and develop innovation competence and teamwork competence. Universities should actively encourage students to actively participate in competitions and provide comprehensive support, including faculty mentoring, adequate laboratory space and equipment, and necessary financial resources. During competition preparation, instructors should guide students to move beyond conventional patterns of thinking and encourage them to propose novel design concepts and solutions [21, 22]. At the same time, after each competition, timely reflection and evaluation should be conducted, and the experience and outcomes gained should be incorporated into regular teaching, thereby using competition to promote both learning and innovation. Challenge- and competition-based training should be systematically connected across all four undergraduate years to ensure horizontal coherence of disciplinary knowledge and progressive development in depth and complexity. A tiered and progressive training framework should therefore be established so that students can gradually accumulate experience, strengthen competence at different stages of study, and transform theoretical knowledge into innovative practical outcomes.

Taking competition-based practice at Northeastern University as an example, the university organizes internal selection to support students' participation in engineering innovation projects and submits selected entries to national competitions for evaluation. In the Second National Innovation Engineering Competition in 2025, Northeastern University recommended 38 entries, among which undergraduate entries received six First Prizes, eleven Second Prizes, and eight Third Prizes, resulting in a substantial body of student project outcomes. The competition assessed students' theoretical understanding, application of innovation tools, and presentation of project outcomes through a theoretical examination, a computer-based innovation software examination, and a project roadshow and defense. These implementation results indicate that the engineering innovation activities organized by the university have generated student outcomes that are both demonstrable and assessable, reflecting the role of competition-based training in connecting knowledge application with project practice. However, these outcomes represent institution-level evidence, and their correspondence with the training scheme proposed in

this study still requires further analysis based on specific courses and training records.

3.3. Technology Empowerment: Developing Digital and Intelligent Platforms

With the continuous development of digital technologies and artificial intelligence, digital and intelligent platforms have become an important direction for practice-based teaching reform. A digital and intelligent practice-based teaching platform for mechanical engineering can integrate advanced technologies such as virtual simulation, digital twins, and artificial intelligence to provide students with immersive and interactive learning experiences. Students can conduct experiments involving mechanical design, simulation of manufacturing processes, and simulation of equipment operation in virtual environments, thereby reducing equipment damage and safety risks caused by operational errors. Such platforms can also overcome temporal and spatial constraints, enabling students to learn and practise anytime and anywhere. For example, digital twin technology can be used to model complex mechanical equipment, allowing students to examine its internal structure and operating principles and gain a deeper understanding of the behavior of mechanical systems. In addition, digital and intelligent platforms can apply learning analytics to students' learning behavior and experimental data to provide instructors with targeted feedback, enabling timely adjustment of teaching strategies and support for personalized learning.

The development of virtual simulation courses at Northeastern University provides concrete support for practical teaching in mechanical engineering. Virtual Simulation Experiment for CNC Machining and Mechanical Engineering Innovation Training: Comprehensive Virtual Simulation Experiment for Mechanical Innovation were both recognized as provincial first-class courses for virtual simulation experiment teaching in Liaoning Province, representing course development achievements that cover both machining practice and mechanical innovation training. These course developments demonstrate that virtual simulation teaching in mechanical engineering has been implemented through specific courses, providing a resource base for connecting theoretical knowledge with practical tasks. In terms of evaluating implementation outcomes, provincial-level course recognition reflects achievements in course development, whereas the development of students' abilities in knowledge application, solution design, and innovation still needs to be examined through course assessments, student work, and records of the experimental process.

3.4. Flexible Innovation: Conducting Modular Innovation Experiments

Modular innovation experiments move beyond the boundaries of traditional laboratory courses by organizing mechanical engineering practice-based learning content into multiple independent and interconnected modules, each centered on a specific innovation theme. Students can select different modules for learning and practice according to their interests and strengths, thereby exercising greater autonomy, initiative, and engagement [23, 24]. For example, mechanical systems or innovation platforms can adopt a LEGO-like modular architecture that allows different functional modules to be flexibly combined. Modules may include mechanical-structure innovation, intelligent control, mechatronic innovation, and so on. During these modular experiments, students are required to apply multidisciplinary knowledge, independently design experimental schemes, select appropriate methods, and solve problems encountered during implementation, thereby developing comprehensive innovation competence and interdisciplinary thinking. The content of modular experiments can also be updated and optimized in response to industry development and technological advances, ensuring the currency and practical relevance of practice-based teaching.

3.5. Comprehensive Enhancement: Constructing Comprehensive Innovation Experiments

Comprehensive innovation experiments not only serve as a comprehensive assessment of students' ability to apply knowledge in an integrated manner and their innovative capabilities, but also foster their ability to construct and integrate knowledge. Such experiments are usually based on authentic engineering projects or complex mechanical systems and require students to comprehensively apply their knowledge in various fields, including mechanical design, mechanical manufacturing, mechanical control, and mechanical testing. Using an integrated experimental platform, students complete the entire engineering process from conceptual design and component manufacturing to assembly, system control and feedback, commissioning, and operation. During the experiment, students will encounter a variety of complex real-world problems, such as the integration of multidisciplinary knowledge, the optimization of design parameters, and the improvement of system performance. These challenges encourage them to explore new

methods and technologies and thereby develop innovation awareness and innovation competence. For example, in a comprehensive innovation project centered on the design of an intelligent logistics-handling robot, students may need to complete the design of mechanical structures design, product manufacturing, the selection of a drive system, developing a control system, and system integration. Through teamwork and iterative innovation, students strengthen their competence in knowledge integration and construction as well as their comprehensive innovation competence.

3.6. Research-Led Innovation: Strengthening Research and Innovation Training

Research and innovation training enables students to participate in authentic research projects, engage with current research topics and methods in their field, and develop students' research literacy and innovation competence. Universities should encourage senior students to work in laboratories, especially national, provincial, and ministerial key laboratories and research platforms. Faculty members should also be encouraged to transform ongoing research projects into practice-based learning resources and involve students in part of the research tasks [25], such as experimental data acquisition and analysis, the design and manufacturing of small components, and basic algorithm development. Under the guidance of research mentors, students can gain an in-depth understanding of the research process, learn scientific reasoning and research methods, and develop independent thinking and innovative spirit, thereby laying a solid foundation for subsequent research. Meanwhile, research and innovation training can also provide students with opportunities to publish academic papers and apply for patents, further strengthening students' motivation for innovation and sense of achievement and laying a foundation for the development of postgraduate students who focus on research or engineering practice.

3.7. Collaborative Education: Deepening Industry-Education Integration

Industry-education integration is an important pathway for cultivating high-caliber research-oriented talent. Universities should build strong partnerships among leading disciplines, key industries, and leading enterprises, organize co-teaching by industry experts and university faculty, and establish a co-teaching model, turning the Lab into a Practical Training Factory. By integrating authentic enterprise environments with university teaching settings, laboratories can provide students with platforms for internships and practical training. By deepening the integrated innovation and cooperation mechanism of industry-university-research-application, and fully leveraging the strengths of industry-academia-research collaboration, enterprises can work jointly with universities and research institutes to establish strategic alliances for industrial technological innovation and a stable Industry-University-Research Cooperation Base. Students can undertake industry placements and participate in authentic production projects and technology research and development activities. During these placements, students can understand current industry developments and actual enterprise needs, integrate theoretical knowledge with production practice, identify problems, and propose innovative solutions, thereby strengthening innovation awareness, innovation competence, and innovation outcomes. Meanwhile, industry engineers can also participate in university practice-based teaching by delivering lectures, supervising internships and capstone design projects, and introducing advanced technologies and management practices into university teaching. In addition, universities and enterprises can jointly undertake research projects and co-supervise postgraduate students, creating mutually beneficial outcomes for universities, enterprises, and students and cultivating more high-caliber innovative talent who meet enterprise needs in the mechanical industry.

The practical teaching reforms described above are implemented from multiple perspectives, including experimental content, task organization, technological support, and engineering application. Verification-based experiments focus on fundamental principles and operational training, while modular and comprehensive experiments emphasize knowledge integration and system design. Competitions, research activities, and enterprise-based practice provide different types of open-ended tasks. During implementation, the teaching objectives and expected outcomes of each type of activity should be clearly defined, and faculty, equipment, and platform resources should be allocated appropriately. The arrangement and articulation of these practical components across the four-year undergraduate program are described in detail in the following section. Figure **1** presents representative tasks and teaching scenarios in the basic, intermediate, and advanced practical teaching modules, including process planning and equipment design, advanced manufacturing practice, and virtual simulation and digital twin experiments. It illustrates the content arranged at different levels of practical teaching.

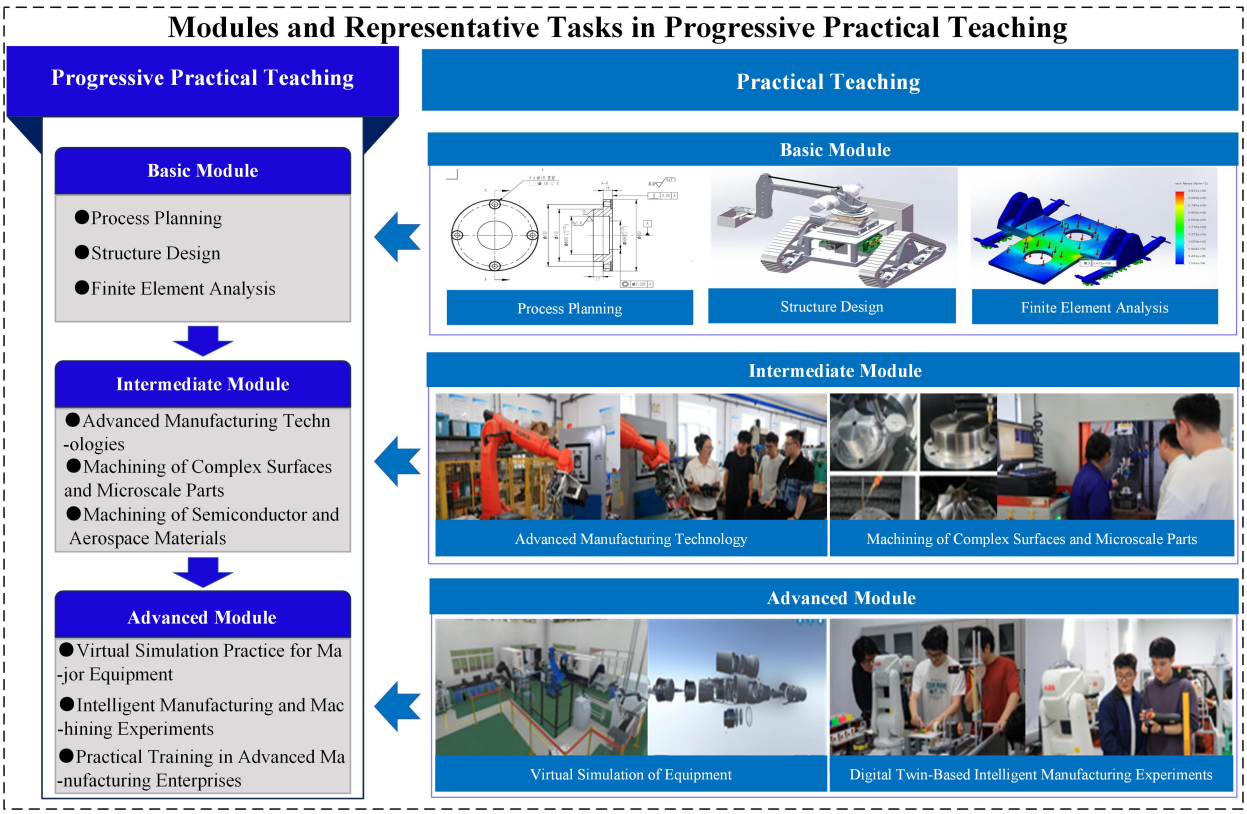


Figure 1: Modules and representative tasks in progressive practical teaching.

4. CULTIVATING INNOVATION COMPETENCE

Building on the teaching measures described above, the cultivation of innovation competence also needs to address the articulation among different courses and practical components. To this end, practical tasks across the four-year undergraduate program should be coordinated according to students' knowledge foundations and stages of learning, with clear definitions of stage-specific outcomes and their intended use in subsequent learning. This section focuses on the organization of cross-year projects and the corresponding requirements for developing competencies, illustrating how different teaching measures can be integrated into a continuous learning process.

4.1. Integrated Development through Practice-Based Teaching

The cultivation of mechanical engineering talent centers on innovation competence and practical competence and is supported by an integrated practice-based learning platform. In cultivating high-caliber mechanical engineering talent, the effective articulation of practical components is crucial. These components should be systematically arranged throughout the four undergraduate years to form an integrated theory-practice education system based on practising through knowing, seeking knowledge through action, and integrating knowledge and action. For example, a continuous four-year system of project-based challenge tasks can be established around a progressive path for developing competencies in mechanical engineering students. In the first year, students focus on basic unmanned aerial vehicle (UAV) design, including principles and modeling of mechanical structures, to gain initial exposure to the fundamentals and hands-on practice of mechanical design. In the second year, training advances to UAV manufacturing processes and experiments in control technology, enabling students to gain an in-depth understanding of manufacturing workflows and control technologies. In the third year, core disciplinary courses are combined with aerial stability control experiments on a single UAV based on multi-sensor fusion, strengthening students' ability to apply multi-sensor fusion and their research competence in stability control for a single UAV. In the fourth year, the graduation design project serves as a vehicle for developing a system for coordinating multiple UAVs based on artificial intelligence algorithms. This sequence supports progressive development of practical competence and innovation competence so that students possess a high level of integrated practical and innovative competence before graduation.

The implementation of a four-year integrated training framework should be based on the continuous use of stage-specific outcomes. Structural models, design reports, and experimental records generated in earlier courses can serve as inputs for subsequent tasks involving manufacturing, control, and system integration. When students progress to a new stage of learning, they should re-examine the assumptions and constraints of existing solutions and revise them in response to new task requirements. Instructors from related courses should jointly define the requirements for transferring these outcomes across stages. Project portfolios should be used to preserve design versions, test results, and the evidence supporting subsequent improvements, enabling students to continuously analyze and refine their solutions on the basis of prior work while reducing repetitive training in different courses that covers similar content but remains disconnected.

4.2. Advancing Innovation Competence

The development of mechanical engineering students' capabilities is reflected not only in the increasing complexity of practical tasks, but also in the expanding scope of knowledge application and the growing degree of independent task completion. As shown in Figure **2**,

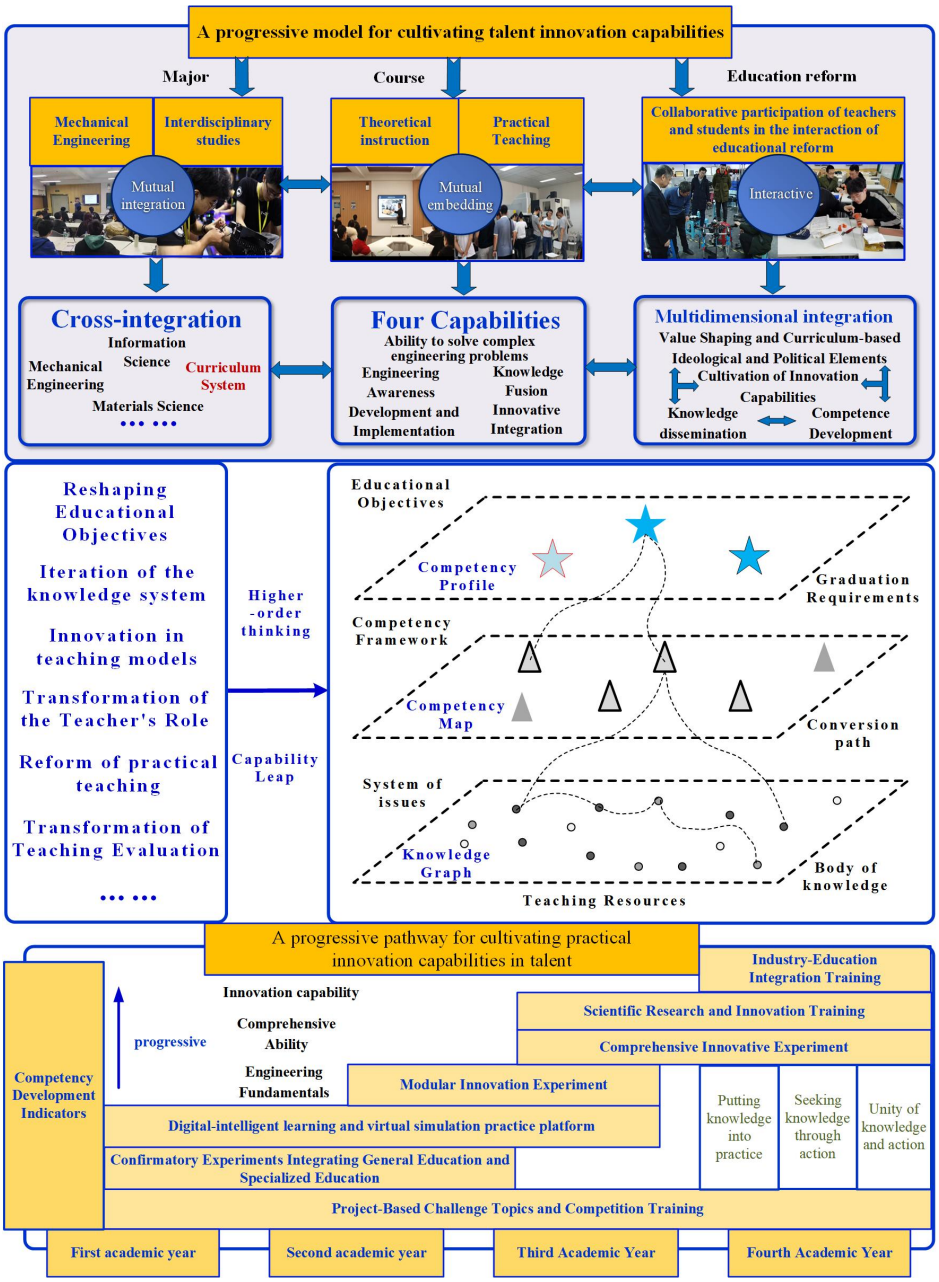


Figure 2: Implementation Pathway for Advancing Innovation Competence in High-Caliber Mechanical Engineering Talent.

the training requirements progressively develop from understanding fundamental principles and completing operational training to integrating knowledge across courses, designing system-level solutions, and analyzing real-world engineering problems. The different stages are connected through continuous tasks, while the level of instructor guidance is gradually adjusted according to students' performance, guiding them from completing tasks by following prescribed procedures toward independently proposing solutions, conducting validation, and making improvements.

The training arrangements described above should be continuously adjusted according to students' task performance. Based on stage-specific work, experimental records, and participation in discussions, instructors can identify students' difficulties in knowledge understanding, solution selection, and implementation and validation, and then adjust subsequent tasks and guidance accordingly. By preserving records of students' design and improvement processes, evidence can be provided for evaluating the extent to which the training objectives at different stages have been achieved. To illustrate the implementation of the teaching practices, this study compiled course grade and innovation competition data over three years, as shown in Figure **3**. Specifically, Figure **3**(**a**) presents the grade distribution for the course *Fundamentals of Mechanical Manufacturing Technology*,

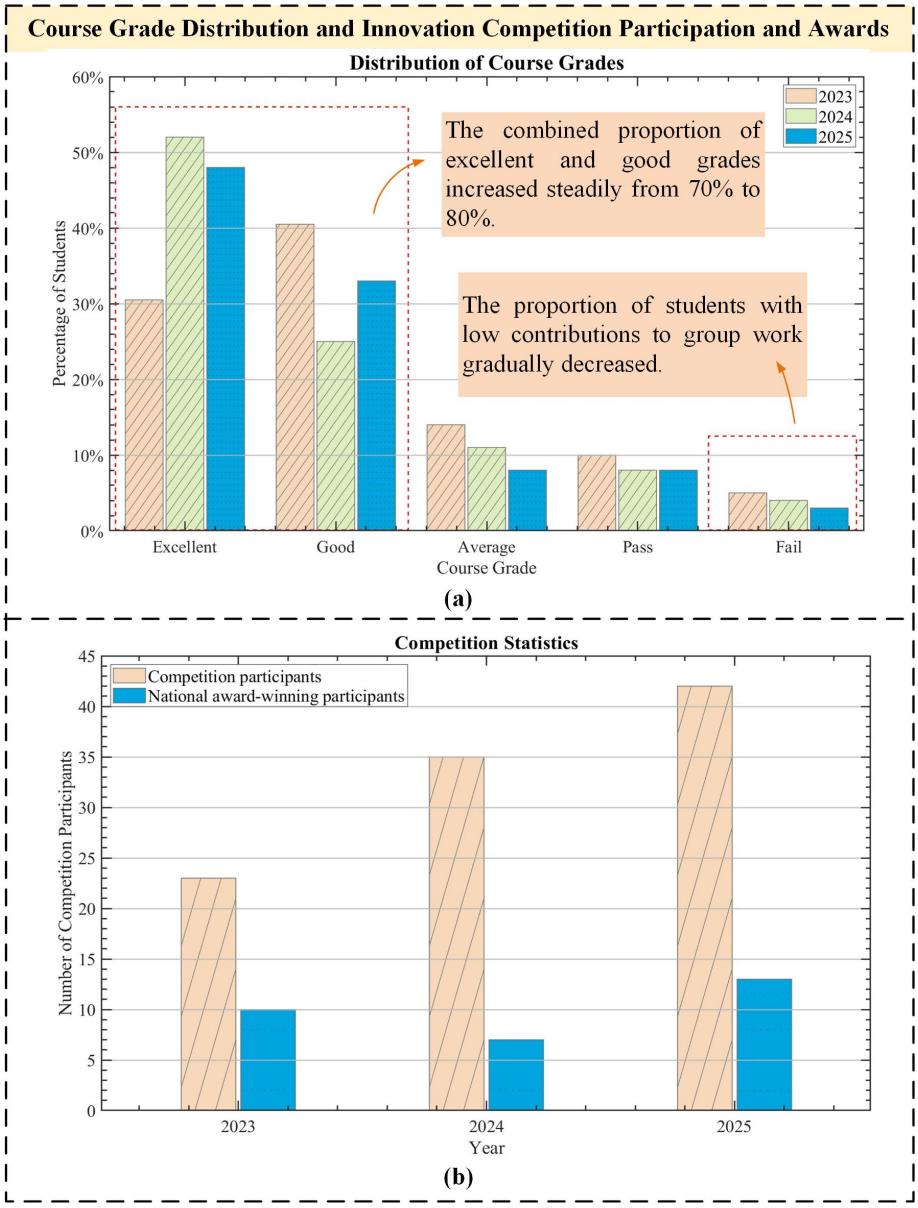


Figure 3: Course grade distribution and innovation competition participation and awards, 2023-2025. (**a**) Grade Distribution for the Course *Fundamentals of Mechanical Manufacturing Technology*; (**b**) Competition Participation and Awards (Two pilot classes in mechanical engineering, one with 42 students, the other with 43).

while Figure **3**(**b**) shows the number of students who participated in the competition and the number who won national awards.

5. CONCLUSIONS AND PROSPECTS

The cultivation of high-quality mechanical engineering talents has long been faced with the dilemma of insufficient adaptation to enterprise demands. The traditional training mode cannot meet the intelligent and high-end development needs of the manufacturing industry. By establishing a mechanical engineering talent development model of practising through knowing, seeking knowledge through action, and integrating knowledge and action, implementation pathways are established for coordinated interdisciplinary integration across mechanical engineering and related fields, the mutual embedding of theoretical and practice-based teaching, and interactive teacher-student seminars that promote reciprocal learning. Within the practice-based education system, verification experiments are optimized to strengthen foundational learning, digital and intelligent platforms are used to innovate teaching methods, and modular and comprehensive innovation experiments strengthen knowledge integration and application. Together with challenge- and competition-based training, research and innovation activities, and industry-education integration, these components establish a platform comprising basic experiments, advanced experiments, comprehensive training, and innovative practical applications. This helps foster an environment conducive to cultivating high-caliber, outstanding engineering talent, strengthens students' thinking competence, practical competence, and innovation competence, and lays a solid foundation for developing their competence in solving complex engineering problems.

In the future, the cultivation of mechanical engineering talent can be further refined in response to developments in manufacturing technology and the implementation of teaching practices. In curriculum development, stronger connections should be established among mechanical design, manufacturing, and control, while relevant content such as intelligent manufacturing can be incorporated as appropriate. Greater attention should also be given to the application of mathematics, natural sciences, and fundamental engineering knowledge in practical tasks. In terms of teaching platforms, tools such as virtual simulation and digital design and manufacturing can be introduced according to actual needs to support solution comparison, operational training, and performance testing. With respect to the organization of practical teaching, stronger articulation should be established among foundational experiments, comprehensive design, research training, and enterprise-based projects, enabling students to apply and extend previously acquired knowledge through continuous tasks. Meanwhile, student work, experimental records, and stage-specific assessments can be used to evaluate the extent to which the teaching objectives have been achieved, progressively refine task design and instructional guidance, and provide a basis for subsequent teaching adjustments.

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CONFLICT OF INTEREST

The authors declare no conflict of interest regarding the research, authorship, and publication of this article.

AUTHOR CONTRIBUTIONS

Lida Zhu: Conceptualization, methodology, investigation, formal analysis, and writing (original draft).

Yao Sun: Methodology, data curation, formal analysis, and writing (review and editing).

Jiayao Chen: Literature organization, language editing, and manuscript formatting.

All authors have read and approved the final manuscript.

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