

Original Research Article

Exploration of the Mechanical Engineering Graduate Training Program: A Synergistic Approach Incorporating Three-in-one and Four-dimensional Linkage Training Mechanism

ABSTRACT

In the context of the new engineering disciplines, the talent requirements for mechanical engineering have evolved, and there is an urgent need for improvement in the training path for high-level professional master's degree students with a focus on future practical applications. In current training programs, many universities have already recognized the importance of incorporating industry practices and interdisciplinary approaches. However, there are diverse ways in which different universities approach industry practices and implement interdisciplinary paths. Therefore, it is crucial to develop training programs that meet the requirements of talent in the new era. By analyzing the policies of outstanding universities and combining them with the characteristics of our own institution, we propose a "trinity" and "four-dimensional" approach to the training of graduate students in mechanical engineering. This framework aims to provide reference and guidance for the instructional design and practical implementation of related disciplines.

Keywords: Mechanical engineering, professional master's degree students, educational reform, new engineering disciplines

1. INTRODUCTION

Under the guidance of the work principles of "cultivating virtues, serving needs, enhancing quality, and pursuing excellence," China's graduate education has made tremendous achievements and is steadily moving towards becoming a powerhouse in graduate education^[1]. Concurrently, there have been significant changes in the structure of graduate programs in China. The number of professional degree graduate students has increased from 35% a decade ago to the current 58%, making them an integral part of graduate education^[2]. The State Council's Academic Degrees Committee and the Ministry of Education have also emphasized the importance of developing professional degree graduate education in the "Development Plan for Professional Degree Graduate Education (2020-2025)." They state that the development of professional degree graduate education is an inevitable choice for entering the high-quality development stage of the economy and society, a crucial path to actively serve the construction of an innovative country, and a strategic focus for degree and graduate education reform and development^[3]. The Ministry of Education's "Guidelines for the New Engineering Research and Practice Program" divides "new engineering" into five parts: new concepts, new structures, new models, new quality, and new systems, aiming to construct a new engineering system. In the context of major national strategies such as "rejuvenating the nation through science and education," "building a strong talent-oriented nation," and "driving development through innovation," as well as the national action plan "Made in China 2025" and the goal of "30/60 carbon peak and carbon neutrality," universities are actively discussing and formulating the construction of the new engineering discipline through initiatives such as the "Fudan Consensus," "Tianjin University Action," and "Beijing Guidelines." These initiatives also set forth requirements that better align with the modernization efforts^[4].

Mechanical engineering, as a traditional discipline in the field of engineering, is one of the key majors driving the revitalization of the manufacturing industry. Countries around the world have conducted considerable exploration in the training of graduate students in the field of mechanical engineering [5-7]. In China, graduate students specializing in mechanical engineering serve as an important force in the delivery of "new engineering" talents. Under the new requirements, these graduate students exhibit distinct characteristics. Therefore, further research on educational pathways and teaching reforms is necessary to cultivate highly skilled applied, interdisciplinary engineering and engineering management professionals with a solid foundation, strong engineering practical abilities, and innovative capabilities [8].

This article aims to analyze the current status of graduate training in mechanical engineering, compare policies across various institutions, and formulate and implement a tailored teaching reform plan for graduate students pursuing professional degrees in mechanical engineering that aligns with the training of "new engineering" talents.

2. A BRIEF OVERVIEW OF THE CURRENT STATUS OF GRADUATE EDUCATION IN MECHANICAL ENGINEERING IN CHINA.

The professional degree graduate education in China has undergone 30 years of reform and development, achieving significant breakthroughs in the quality and quantity of graduate students. Especially in the case of professional degree graduate students, their numbers and proportions have greatly increased. However, under the new development concept, the educational values and talent cultivation models of professional degree graduate students need to keep pace with the times. There are still many areas where we fall short compared to the professional degree graduate education in developed countries. Therefore, it is necessary to further improve and perfect the distinctive Chinese professional degree system.

Most colleges and universities in China offer machinery-related majors. The comprehensive and objective evaluation of mechanical engineering by the fourth round of disciplinary assessments has provided insights into the goals and training programs for professional degree graduate students in mechanical engineering from universities rated as A+, A, and A-. By analyzing the specific policies of various universities, we can summarize and analyze the target settings and training methods employed in graduate education for the mechanical industry. This analysis will help in formulating a more tailored graduate training program for the mechanical engineering discipline at our university [9].

Table 1. Key elements of the training path at top universities in the field of mechanical engineering.

Colleges	Develop target key phrases	Cultivation methods
Tsinghua University	Oriented to the needs of enterprises; character development; professionalism; High-level application-oriented professionals with innovation and entrepreneurship	<ol style="list-style-type: none"> 1. Guided by career needs, focusing on practical ability training, and combining industry and academia as the way, it serves the strategic needs of the country and establishes a professional degree postgraduate training model with Chinese characteristics and Tsinghua style. 2. Dual mentors 3. Strengthen practical links.
Harbin Institute of Technology	All-round development; Solid theory in this major; Independent thinking, international vision, cultural accomplishment; High-level engineering and technical talents in mechanical engineering	<ol style="list-style-type: none"> 1. The training mode combining a variety of training methods, such as cooperation with China and foreign countries, school-enterprise cooperation and laboratory training, etc., will gradually implement the training mode of teaching according to aptitude and professional education. 2. On-campus tutor responsibility system + off-campus tutor assistance.

Shanghai Jiaotong University	moral literacy; Solid foundation in mathematics and physics; broad knowledge structure; Proficient in professional domain knowledge; Strong innovation ability; Have a sense of social responsibility; International vision and international competitiveness; Professionals at the forefront of mechanical engineering	<ol style="list-style-type: none"> 1. Strengthen the practice platform 2. Diverse practices
Hust	Basic knowledge of machinery and expertise in systems; Ability to research practical problems; Cultivate a rigorous and realistic learning attitude and work style	Evaluation of diversified practices
Beijing Institute of Technology	moral literacy; Basic theory and expertise; Strong ability to analyze and solve practical problems; Management, practice and innovation	<ol style="list-style-type: none"> 1. Diverse practices 2. Dual mentor responsibility system (
Tianjin University	3I•4C" classification culture system to cultivate moral literacy; professional competence; practical ability; integration of disciplines; International training	<ol style="list-style-type: none"> 1. The five dimensions (scientific research, mentors, student sources, knowledge structure and training mode) are promoted to promote cross-integration. 2. Four levels (training mode, quality evaluation, teaching system, academic exchange) collaboration to promote open innovation.
Dalian University of Technology	character education; Practical engineering skills; comprehensive ability to innovate; Ability to apply knowledge; Cutting-edge vision in the field has industry leadership potential; Composite engineering technology and management talents	<ol style="list-style-type: none"> 1. Dual mentor training 2. Strengthen practice, and some students adopt an order-based training model.
Zhejiang University	Basic moral literacy; For machinery industry enterprises; Theory; System expertise+; advanced technological methods and modern technical means; Sense of innovation and the ability to independently undertake engineering technology or engineering management work; Application-oriented, composite high-level engineering technology and engineering management senior talents	<ol style="list-style-type: none"> 1. Integrated interdisciplinary practice 2. Project-based teaching in a continuous mode
Xi'an Jiaotong University	Provide services to industrial and mining enterprises and engineering construction units; all-round development of morality, intellect and body; Theory; Expertise; Required experimental skills; Ability to solve practical engineering and technical problems; the mechanical engineering aspects of the ability to apply the achievements of modern science and technology; High-level engineering technology and engineering management talents.	<ol style="list-style-type: none"> 1. Dual mentorship 2. Leverage corporate enthusiasm
Beihang University	For the aerospace field; Master the overall design, basic concepts and theories of spacecraft; High-level comprehensive research ability of overall system design, analysis, experiment and testing; engineering practice; High-level application-oriented and composite engineering and management talents	School-enterprise joint training
Jilin University	moral literacy; the ability to innovate; For solving major projects; Application-oriented, composite high-level engineering technology and engineering management talents	<ol style="list-style-type: none"> 1. School-enterprise dual tutors 2. Combine concentrated practice with segmented practice
Yanshan	moral literacy; Innovative spirit; Expertise;	<ol style="list-style-type: none"> 1. Concentrated practice

University	professionalism; Teamwork spirit, healthy physique and good psychological quality; Application-oriented, composite high-level engineering technology and engineering management talents	combined with segmented practice 2. Combine on-campus practice with off-campus practice 3. The graduation thesis is required to be combined with practice
Shanghai Jiao Tong University	ideological character; the spirit of solidarity; foundational competencies; Application ability; High-level application-oriented talents in mechanical engineering	1. School-enterprise cooperation 2. Project support
Nanjing University of Aeronautics and Astronaut	ideological and moral literacy; Expertise; Sense of responsibility, innovative spirit, international vision and humanistic feelings; professionalism; Compound and application-oriented high-level talents that meet the needs of society or industry.	1. School-enterprise dual tutors 2. Grading, classification, classification settings
Hunan University	For industrial and mining enterprises and engineering construction departments; ideological and moral literacy; Theory combined with practice; Application-oriented and composite high-level engineering technology and engineering management talents with professional basic knowledge.	1. Diversified dissertation formats such as dissertations, survey reports, design reports, etc 2. Mixed tutor system (school-enterprise dual tutor or on-campus tutor-based model).
Central	cultivate ideological and moral literacy; Good scientific research attitude and work style; Excellent professional skills; the ability to solve practical problems; High-level application-oriented compound professionals	Dual tutors inside and outside the school
South China University of Technology	Excellent ideological and moral literacy; Solid foundation; Comprehensive quality; Innovation ability and management ability; Application-oriented, composite high-level engineering technology and engineering management talents	1. It adopts a "three-stage" training method, that is, "course learning + professional practice + dissertation". 2. School-enterprise dual tutors 3. Classification and culture are carried out for different sources.
Chongqing University	All-round development of moral, intellectual, physical, aesthetic and labor; Excellent basic knowledge; Innovative and entrepreneurial; Correct work ethic; High-level application-oriented professionals	1. School-enterprise dual tutor training 2. A combination of concentrated practice and segmented practice.

3. PROBLEM ANALYSIS.

From the objectives and approaches for cultivating graduate students in the field of mechanical engineering across various universities, we can observe the concerted efforts made by these institutions in nurturing talents for the emerging disciplines. The educational objectives of these universities are generally aligned, **Take advantage of the characteristics of our university in the context of meeting the requirements of our new engineering talent.** However, there is a lack of emphasis on interdisciplinary training in the educational objectives set by universities. For the development of new engineering disciplines, interdisciplinary talents are indispensable ^[10]. Furthermore, all universities emphasize the cultivation of professional master's degree holders into "high-level applied talents." While most institutions mention the dual mentorship system involving collaboration between the university and industry, **dual mentors refer to off-campus mentors and on-campus mentors, respectively.** Among them, on-campus tutors are mainly responsible for theoretical knowledge and research, while off-campus tutors, i.e. tutors in enterprises, focus on combining theoretical knowledge with **actual production.** The execution of such programs varies. This discrepancy manifests in the different approaches to practical training. Specifically, the following models are observed: (1) Dual mentorship system with university-based mentors taking the lead while external mentors provide supplementary guidance. Under this model, different mentors are responsible for different aspects of student development. **Dual tutors are set up at the time of admission, with an on-campus tutor for academic training and an off-campus tutor for practical training.** (2) Dual mentorship system with segmented student development, where in mentors assume responsibility for specific stages of the students' training. During certain periods, students engage in internships facilitated by industry mentors, while the remaining time is spent under the guidance of university mentors. (3) Dual mentorship system where university mentors oversee academic

development while industry mentors are responsible for guiding students during practical experiences. This approach relies on the location of students, with different mentors assuming responsibility based on the specific context. There is no distinct separation of internship periods, as students' engagement in industry practices spans their entire graduate studies. (4) Dual mentorship system with two university-based mentors, consisting of an academic-oriented mentor primarily responsible for training, and one or more experienced mentors from the industry focusing on practical training. **The difference with several other models is that the entire process of student development is entirely within the school.** (5) Dual mentorship system with a blended approach using multiple methods, offering flexible choices based on students' actual training needs.

It is evident that for the cultivation of applied talents, universities acknowledge the effectiveness of implementing a collaborative mechanism between academia and industry to enhance students' practical abilities. However, there are slight variations in the execution methods, requiring further integration of each university's characteristics to explore efficient models for the development of professional degree graduate education. In the exploration of the training model for graduate students in the field of mechanical engineering, the following issues still exist:

(1) Insufficiently developed university-industry collaboration system:

The phenomenon of insufficient or too close integration with enterprises in the training of postgraduate students of mechanical majors in colleges and universities. This is primarily demonstrated by the fact that students, upon graduation, are still unable to meet the standards of being immediately employable by companies. The reasons behind this include the lack of talent development models that respond to industry demands, the establishment of faculty teams embodying a dual-mentorship approach, and the construction of curriculum systems^[11]. Within the realm of practical experiences offered by universities, such experiences are mostly short-term in nature, failing to provide in-depth understanding of the working processes within companies and the actual work environment. Consequently, students lack the adaptability and foundational skills for future planning, resulting in a disconnect between their research and practical applications in enterprises. As a result, students often require significant additional training in enterprise-related knowledge after employment, while companies also need to allocate substantial resources to educate these students, leading to inefficiencies.

Furthermore, in the training process of professional degree graduate students, some universities completely entrust the students to companies for training, thereby weakening the roles of the universities and mentors. This practice turns students into "cheap labor" for companies, neglecting their identities as graduate students and researchers. It is an unreasonable system that disregards the cultivation of basic qualities in graduate students by universities and mentors. These phenomena mainly stem from the insufficient division of responsibilities in the joint training between universities and enterprises, lack of clarity in the training model, and inadequate implementation. Although many schools have explored university-industry collaboration in training, the specific methods and responsible parties for such collaborations still require further exploration.

(2) Disconnect between university curriculum and practical applications:

In the early stages of exploring professional degree graduate education, many schools lacked specialized courses for professional degree graduate students. **This is demonstrated by the fact that the courses of study are the same for the two different directions of postgraduate training.** However, in recent years, this situation has been rectified through changes in training programs. Distinct requirements and course offerings have been introduced to differentiate between the academic and applied aspects of mechanical engineering education for professional and research degrees. In course design, the values and essential knowledge for enterprise applications are conveyed to students. However, for the development of "new engineering disciplines" that emphasize interdisciplinary approaches, most universities still primarily focus on the academic aspect, catering to the education of research-oriented graduate students. Therefore, there is a lag in the development of new engineering discipline courses for professional degree graduate students^[12]. **This phenomenon is rooted in the fact that there is no immediate interconnection of technical information between universities, tutors and enterprises.** While universities are expected to respond with institutional innovations to accommodate new engineering disciplines, mentors, companies, and other participants in the teaching process often struggle to timely incorporate innovative content into their teaching, resulting in certain teaching aspects falling behind.

(3) Inadequate evaluation mechanisms:

Evaluation mechanisms serve as indicators of the training models employed. In the context of actual teaching, there exists a discrepancy between the evaluation mechanisms for professional degree graduate students and those for research-oriented graduate students, with the former lagging behind. The implementation and effectiveness of evaluation mechanisms for professional degree graduate students during teaching activities have been subpar^[13]. The evaluation

process in professional degree graduate education involves not only students but also teachers, mentors, companies, and other participants in teaching activities. A comprehensive and effective evaluation mechanism helps schools and teachers design precise teaching activities and is equally beneficial for nurturing professional degree graduate students in the context of "new engineering disciplines."

4. INTEGRATED AND INTERCONNECTED MECHANISM FOR PROFESSIONAL DEGREE GRADUATE EDUCATION WITH THREE ELEMENTS AND FOUR-DIMENSIONAL COLLABORATION

In response to the aforementioned issues, guided by the educational philosophy of "focusing on nurturing individuals and applying knowledge," the spirit of "caring for water resources and striving for excellence," and the characteristic of talent development embodied by the motto "being capable, resilient, employable, and competent," we aim to comprehensively enhance the overall competence of graduate students in the field of mechanical engineering. To achieve this, we propose an integrated three-dimensional training framework that encompasses "practical abilities," "professional theories," and "fundamental qualities" as key dimensions of professional degree graduate education. This framework is designed to establish a four-dimensional collaboration and interaction among the participants of the educational process: "students," "enterprises," "universities," and "mentors." From the formulation of training programs and instructional design to the final evaluation and application of talents, this mechanism ensures a comprehensive and interconnected approach to graduate student development.

4.1 INTEGRATED AND INTERCONNECTED THREE-DIMENSIONAL TRAINING PROCESS.

To address the training objectives of graduate students in the field of mechanical engineering, we divide them into three attributes: "students," "researchers," and "future engineers." These attributes correspond to "fundamental qualities," "professional theories," and "practical applications in industry," respectively. In the development of the instructional plan, these three aspects are integrated and updated under the guidance of the training objectives, thereby establishing an integrated three-dimensional training process. This approach breaks the limitations of the traditional training model, such as insufficient integration with industry, a disconnect between university courses and real-world applications, and inadequate evaluation mechanisms.

Regarding the training approach for graduate students in mechanical engineering, we establish a connection between the four participants in the educational process: universities, mentors, students, and enterprises. The interactions among these four entities are emphasized, and it is crucial to understand that educational reform is not merely a transformation of one aspect but rather a change in the relationships among the four aspects. **Simultaneously, the training program and evaluation criteria should reflect collaborative synergy, integration of the plans and objectives of the four participants, improvements made based on the requirements of the objectives and the four participants.** This approach addresses the uneven participation among educational entities in practical teaching, which often leads to difficulties in achieving the intended learning outcomes and a superficial teaching model. The integrated three-dimensional training process with four-dimensional collaboration is illustrated in Figure 1.

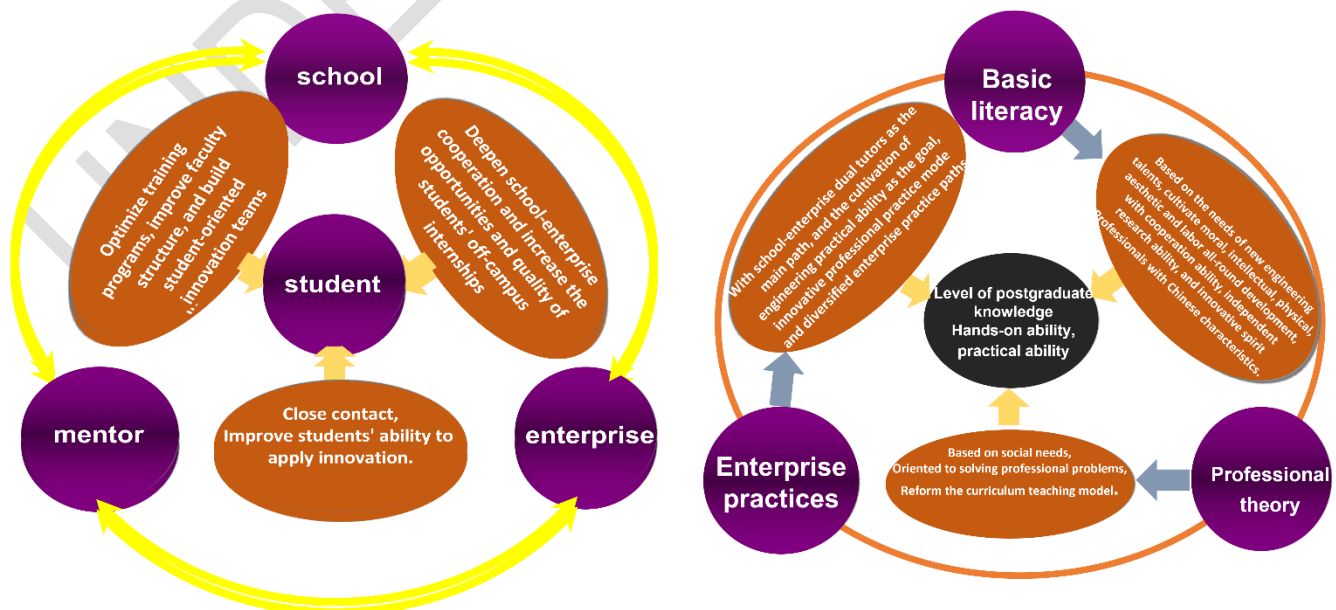


Fig. 1. The Integrated and Interconnected Three-Dimensional Training Process with Four-Dimensional Collaboration

4.2 SPECIFIC IMPLEMENTATION PLAN.

Regarding the curriculum system, the course structure is optimized, and the training objectives are clearly defined. The curriculum for graduate students in mechanical engineering is vertically divided into four major modules, each with different learning objectives. The module of compulsory courses in general education focuses on cultivating students' foundational qualities, while the module of fundamental theory courses mainly develops students' logical and mathematical abilities necessary for scientific research. The school is mainly responsible for coordinating and arranging these aspects, targeting the development of the "student" attribute. The module of professional foundation courses aims to enhance students' theoretical knowledge and practical application skills in the discipline, while the module of elective courses provides students with a wider range of learning choices. To enable students to acquire knowledge of other disciplines involved in practical applications. Horizontally, in addition to the compulsory courses, core courses in mechanical engineering, courses related to sensing and control, courses related to vehicles, as well as courses related to materials are offered, creating three discipline clusters. This allows for interdisciplinary elective courses and a clearer definition of students' training objectives. The responsibility for this lies mainly with the graduate school, the mechanical engineering department, and the student advisors, targeting the development of the "researcher" attribute.

Regarding the classroom content, practical engineering applications are integrated into teaching, test the viability of theoretical knowledge in practical applications. In professional courses, teaching syllabi and instructional capacity are optimized to meet the specific requirements of the emerging engineering disciplines. Teaching content related to engineering applications is added to enhance students' awareness of practical application and innovation. Additionally, general education is incorporated into the classroom, and considering the characteristics of graduate education, life goals, values, research ethos, and innovative spirit are integrated into the curriculum design. In line with the characteristics of mechanical engineering degrees, patriotism, research ethics, engineering ethics, and craftsmanship spirit are integrated into teaching practice to cultivate engineers with a sense of national responsibility.

In terms of faculty resources, the optimization of faculty strength and structure is pursued. On one hand, efforts are made to concentrate expertise in certain faculty members to form the backbone of specific discipline clusters. Faculty structure is optimized, and faculty members are encouraged to participate in training programs for academic degrees and practical capabilities. On the other hand, enterprise mentors with teaching expertise are hired. Corporate tutors and on-campus tutors regularly communicate and formulate training programs, promoting information sharing between training units and industries. The purpose of student practice is to deepen their research capabilities and enhance their practical skills. The school, mentors, and enterprises work together to provide the necessary conditions for improving these skills. The collaboration between these three parties establishes a high-level teaching team that combines scientific research and practical engineering capabilities, possesses an international perspective, has a reasonable distribution of academic titles and qualifications, and fosters collaboration and cooperation among experienced, intermediate, and young faculty members. The faculty members in the university are oriented towards engineering, while externally hired teachers focus on research. The aim is to combine going out and bringing in, strengthen exchanges and integration between experimental teachers with a research background and those with an engineering background. Efforts are made to strengthen the exchange and integration between experimental teachers with a research background and those with an engineering background. An incentive system is implemented to support the promotion of excellent teacher teams. Additionally, attention is given to interdisciplinary collaborations, fostering multidisciplinary and integrated talents. On one hand, efforts are made to attract cross-disciplinary talents with a mechanical engineering background to explore new directions in emerging engineering education. On the other hand, the recruitment channels for graduate students are expanded by widening the threshold for admission to the mechanical engineering program, allowing students from related disciplines to apply. At the same time, it expands the students' knowledge and enables them to integrate more quickly into real production work.

In terms of university-industry cooperation, the school leverages its educational advantages by seeking collaboration with outstanding enterprises in relevant disciplines to establish internship bases. Close attention is given to the review of teaching content and the development of internship plans in these enterprises. Multiple internship methods are adopted, with a priority given to project-based internships. This involves collaboration between enterprises and universities, where students and employees form teams to work on project-based development during the internship period. Practical production life in the enterprise, combining theory and practice, further verifying the practicality of the theory. On one hand, project-based internships allow students to acquire communication skills commonly used in enterprises. On the

other hand, collaboration between the school and enterprises helps to maintain effective communication channels, ensuring the validity of internships.

Furthermore, the university implements various internship methods to accommodate students who may not be able to participate in project-based internships due to limited resources. This may involve traditional internships or other forms of university-industry cooperation. In such internships, close communication is maintained between internal and external mentors to jointly supervise students' research progress and directions. The connection between the school and enterprises is also maintained to make real-time adjustments to the internship plan and positions. Student selection is tailored based on minor adjustments to the positions, aiming to provide the most needed and suitable off-campus internship opportunities for students. During the summer break, small-scale short-term internships are provided, allowing students to gain a deeper understanding of the technologies currently applied in the industry. The respective responsibilities of university-industry dual mentors are shown in Figure 2.

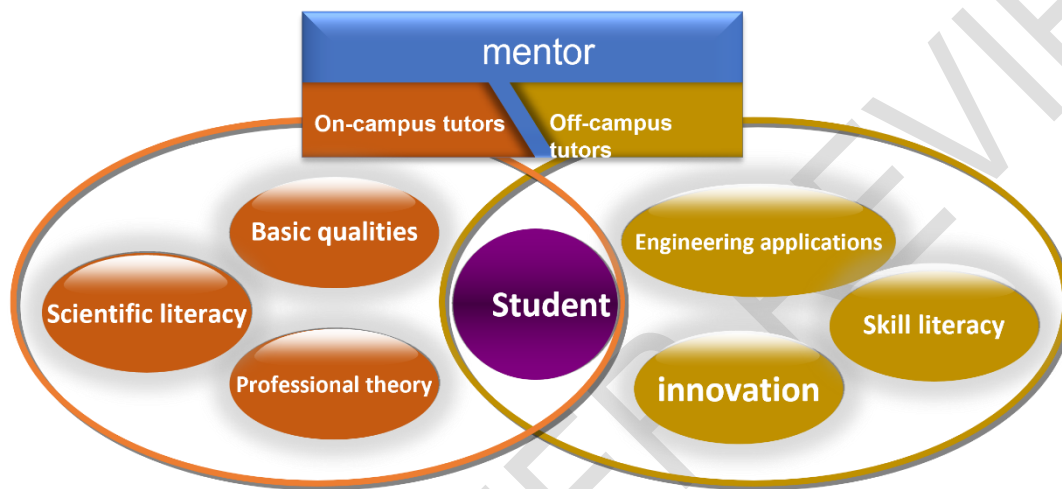


Fig. 2. The training responsibilities of different entities in the school-enterprise dual mentor system

In terms of student training, for professional master's degrees, the evaluation and recognition system highlights the characteristics of professional degrees and increases the weight of factors related to innovation and application. This includes building a student academic research team that focuses on professional knowledge through extracurricular learning, professional skills training, project report writing, thesis publication, patent application, teamwork, and collaboration. The system leverages the mentoring role among students of different academic levels, and emphasizes the integration of competitions into teaching and learning, providing opportunities for the application of knowledge. Regarding the standards for students' graduation theses, professional master's students should demonstrate engineering, applicability, and practicality. The approach should be diversified, allowing for various formats of graduation outcomes.

At present, the "Three-in-one" and "Four-dimensional Linkage" training mechanism is being implemented according to plan, and according to the course results, research results and employment situation of the students in recent years, the comprehensive ability of the students has been further improved compared with the previous traditional training program, and the employment situation has also improved.

5. DISCUSSION AND CONCLUSION

In recent years, the comprehensive ability of China's mechanical postgraduates has been improved to a certain extent, there are still many differences among universities. The standards for cultivating talents in the new discipline of engineering set new requirements for students. Through the "three-in-one and four-dimensional linkage" training process, efforts are made to address issues such as inadequate integration of industrial practices in the training process, the gap between university courses and applications, and incomplete evaluation mechanisms for mechanical engineering graduate students.

The "three-in-one" training mechanism ensures that the mechanical postgraduate students' "practical ability", "professional theory" and "basic literacy" develop comprehensively and quickly meet the needs of society. The "four-dimensional linkage" training mechanism ensures synchronous innovation among all participants in the teaching process

and making policy and practice mirror each other in real time. Adhering to the principle of "tailoring policies to suit different schools" and focusing on "specialized cultivation of specialized talents" in policy formulation can maximize the role of professional master's degree graduates in future development.

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