Open Journal of Social Sciences, 2025, 13(3), 404-416
https://www.scirp.org/journal/jss
ISSN Online: 2327-5960
ISSN Print: 2327-5952

Exploring and Practicing a Multidimensional Integration Model for the Cultivation of Outstanding Mechanical Engineering Talents in the Context of New Engineering Disciplines

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How to cite this paper: Li, X. M., Liang, J., & Yang, L. X. (2025). Exploring and Practicing a Multidimensional Integration Model for the Cultivation of Outstanding Mechanical Engineering Talents in the Context of New Engineering Disciplines. *Open Journal of Social Sciences, 13,* 404-416.
https://doi.org/10.4236/jss.2025.133028

Received: February 19, 2025
Accepted: March 16, 2025
Published: March 19, 2025

Abstract

Under the new engineering disciplines framework, Chinese universities are actively exploring talent cultivation models for fields such as mechanical engineering, in response to the latest technological revolutions and industrial transformations. Compared to the goals set by Industry 4.0 and new engineering education standards, the cultivation of outstanding talents in mechanical engineering still faces challenges, such as a scarcity of exceptional talents, an overemphasis on quantitative assessment by teachers and students, a lack of internal motivation, broad but conceptualized content coverage, and a disconnect between theoretical teaching and practical engineering, which often focuses more on form than substance. This paper aims to cultivate outstanding talents in mechanical engineering by adopting a dual-subject, endogenous, progressive training concept. It emphasizes value-driven learning to stimulate internal motivation, reconstructs interdisciplinary knowledge systems following cognitive principles, and integrates industry and education to build a sustainable platform for innovative practice. This exploration of a multidimensional integration model for cultivating exceptional talents in mechanical engineering seeks to provide insights for developing future-oriented engineering and technical talents.

Keywords

New Engineering Disciplines, Mechanical Engineering, Outstanding Engineers, Talent Cultivation Model, Multidimensional Integration

1. Introduction

Against the backdrop of unprecedented global changes, a new round of technological revolution, and deep industrial transformation, talent cultivation has become a crucial national and ethnic long-term strategy. The state promotes innovation-driven development and deepens the reform of engineering education, aiming to build a strong engineering education nation and setting higher standards for engineering and technological talents. Under the leadership of the Ministry of Education, the new engineering disciplines initiative closely aligns with the national development strategies, proactively shaping the cultivation of talents who will lead future technological and industrial advancements. This consensus has been widely accepted within the Chinese higher engineering education community. The “Fudan Consensus”, “Tianjin Actions”, and “Beijing Guidelines” together form a trilogy of new engineering disciplines construction, playing a central theme in talent cultivation and pioneering new pathways for engineering education reform. The cultivation of outstanding talents in mechanical engineering, as a crucial component of the new engineering disciplines, must also undergo profound reforms and innovations to align with the new concepts and demands of the new engineering disciplines’ construction.

2. New Requirements for the Cultivation of Outstanding Mechanical Engineering Talents in the Context of New Engineering Disciplines

In September 2022, 18 China national institutions dedicated to the cultivation of outstanding engineers jointly issued the “Beijing Declaration on Engineer Education”. The Declaration calls for comprehensive reforms in China’s engineering education philosophy, system, and approach in response to the rapid development of engineering practice. It emphasizes the need to address critical issues such as the shortage of high-level talents in key areas and the disconnect between engineering education and the cultivation of engineering capabilities. The Declaration advocates for continuous deep integration of industry and education and significant innovation in talent cultivation models (Yu, 2022). From the “Excellence Initiative” to the “New Engineering Disciplines”, scholars have conducted fruitful research surrounding the educational content and background of new engineering disciplines, the qualities of outstanding engineering talents, and their cultivation models.

2.1. Educational Content and Background of New Engineering Disciplines

Zhong (2017) defined the essence of new engineering disciplines as being guided by moral education and aimed at responding to changes and shaping the future. It involved inheriting and innovating, integrating across disciplines, and fostering future-oriented, diverse, and innovative engineering talents. Scholars like Wu et al. (2017) viewed the construction of new engineering disciplines, as opposed to traditional engineering disciplines, as being grounded in the new economy and industries, tailored to the urgent needs of current industries and future development, and proactive in adapting to and leading the new economy through exploring new educational models suited to the characteristics of our times. Lin (2017) interpreted new engineering disciplines as encompassing emerging, novel, and nascent meanings, characterized by their leadership, integration, innovation, interdisciplinarity, and developmental nature. Li et al. (2017) suggested that new engineering disciplines should incorporate new concepts, models, and technologies integral to engineering education, adapting to the needs of the new economic development and can be described as "Engineering+". Zheng (2020) guided the construction of new engineering disciplines from a strategic orientation, proposing three levels of meaning for their establishment.

2.2. Qualities of Outstanding Engineering Talents

On January 8, 2011, the Ministry of Education issued guidelines for the implementation of the "Plan for Educating and Training Outstanding Engineers", aimed at developing a large number of high-quality engineering and technical talents with strong innovation abilities to meet the needs of economic and social development. On November 28, 2013, the Ministry of Education and the Chinese Academy of Engineering jointly released general standards for the education and training of outstanding engineers, specifying the basic requirements for the cultivation of various types of engineering talents at undergraduate, master's, and doctoral levels. These standards focus on serving national strategies, pursuing excellence in quality, meeting international demands, and providing macro-level guidance. Lin (2017) believed that the main goal of constructing new engineering disciplines was to proactively lay, establish, and build engineering disciplines and specialties that serve national strategies, meet industry demands, and are oriented towards future development, thus cultivating a group of innovative, cross-disciplinary, and high-quality engineering and technology talents (Lin, 2020).

2.3. Cultivation Models for Outstanding Engineering Talents

Based on the general standards for cultivating outstanding talents, universities and scholars have proposed corresponding cultivation models. For example, Guangdong University of Technology has developed a comprehensive system for cultivating innovative talents in new engineering disciplines through interdisciplinary and multi-specialty integration (Li et al., 2020). Tianjin University has innovated in the cultivation of leading engineering talents from aspects such as value leadership, cultivation systems, curriculum systems, educational culture, and educational platforms (Yu et al., 2020). Harbin Institute of Technology has developed the "HIT New Engineering 'Pi-type' Scheme" in engineering education reform, interdisciplinary integration, teaching method innovation, and industry-academia collaboration (Xu et al., 2020). Huazhong University of Science and Technology leads with a practice-driven innovation concept in intelligent manufacturing engineering, constructing an open, collaborative system for cultivating innovative talents in intelligent manufacturing throughout the undergraduate process

(Wang et al., 2022). Liu and Yuan (2021) explored integrating design innovation thinking into new engineering education, proposing the acceleration of new engineering construction through optimizing educational resource allocation, advancing teaching method reform, strengthening interdisciplinary integration across institutions, and promoting interdisciplinary talent cultivation, with innovation and entrepreneurship education integrated throughout. Wang (2021) constructed the innovative dimensions of new engineering talent cultivation models from the perspectives of cultivation philosophy, objectives, and methods. Scholars' research on the educational content and background of new engineering disciplines, as well as the qualities and cultivation models of outstanding engineering talents, provides direction for the multidimensional integration cultivation of outstanding mechanical engineering talents, making it an urgent and important issue to address in line with the general standards for new engineering talent cultivation.

3. Current Issues in the Reform of Multidimensional Integration Training for Outstanding Mechanical Engineering Talents

As the new round of technological revolution intensifies the reshaping of the global industrial landscape, new manufacturing has become the main engine for high-quality economic development of countries. In light of national development strategies and industrial transformation needs for talents, the urgent need in engineering education reform is to cultivate outstanding talents equipped with a sense of national duty, exploratory spirit, scientific and systematic thinking, and engineering capabilities. In the field of mechanical engineering, continuously adding interdisciplinary courses and practical components to cultivate outstanding talents for the new era and exploring a training system for engineers with Chinese characteristics and world standards have become common choices under the new engineering education background. However, there are still significant challenges such as a shortage of outstanding talents for building a strong engineering nation, a focus on quantitative assessments by teachers and students, a lack of intrinsic motivation, broad but conceptualized knowledge coverage, and a disconnect between theoretical teaching and practical engineering that focuses more on formality—issues that need to be addressed to innovate the mechanical engineering education system.

3.1. Shortage of Outstanding Talents for Building a Strong Engineering Nation

From being a major manufacturing country to becoming a powerful one and moving from the middle to the high end of the global industrial value chain, China's engineering education has achieved fruitful results, nurturing countless engineering and technical talents. However, there is still substantial room for growth both in terms of the number of talents and their quality. According to estimates by the China Household Finance Survey and Research Center at the Southwestern University of Finance and Economics, if by 2035 the proportion of engineers in the workforce reaches the current average level of developed countries, the demand for engineers will be about 45 million, with a supply of about 31.911 million. Furthermore, as the manufacturing sector rapidly develops and technology continuously advances, the demand for outstanding engineers also increases, widening the gap between total demand and supply. Additionally, a 2023 survey by Wuhan Manufacturing Information Engineering Technology Co., Ltd. on Chief Information Officers (CIOs) of manufacturing companies indicates that talent issues have become one of the key bottlenecks in achieving effective progress in intelligent manufacturing, with a 10 percentage point increase from 2022 in the proportion of respondents citing "insufficient professional talents."

3.2. Insufficient Motivation among Teachers and Students to Drive Teaching Innovation

Scientific research and industrial development necessitate continuous updates to the mechanical engineering knowledge system, imposing high demands on teachers' teaching involvement and talent training capabilities. Teaching system theory suggests that teachers and students should be the "dual subjects" in the teaching system, representing an organic unity of optimized teaching (teacher activities) and learning (student activities), fully leveraging the agency of both teachers and students. In the context of new engineering disciplines, the continuous renewal of the mechanical engineering knowledge system driven by scientific research and industrial development poses high demands on teachers' teaching involvement and talent training capabilities. On one hand, during the talent training process, schools emphasize quantitative assessments, significantly increasing pressure on teachers who then pursue various assessment data at the expense of focusing on the essential needs of talent cultivation; on the other hand, students, influenced by exam-oriented education, lack long-term vision and motivation, showing little focus on solving practical problems and insufficient initiative in learning. A study on the motivation of engineering students reveals that a lack of understanding of their majors leads to an aversion to studying, with insufficient motivation from a "sense of mission" and "self-challenge", with 52.6% of university teachers noting "low student enthusiasm" and some interviewed engineering students indicating that teachers' content is detached from industry reality and lacks innovation in teaching components. Thus, following the laws of engineering education and the rules of student development and success, promoting a healthy interaction between teaching and learning, exploring the intrinsic motivation of dual subjects, and providing theoretical support for the cultivation of outstanding talents are essential.

3.3. Lagging Knowledge System in Keeping up with Engineering Innovation

The knowledge system of mechanical engineering is experiencing explosive growth, and traditional mechanical engineering education has many drawbacks, such as the traditional disciplines limiting the training of talents due to academic barriers, narrowing the knowledge system of engineering talents; professional barriers restricting the broader engineering perspective, with engineering education lacking in training for composite engineering talents; and narrow curricular knowledge architecture, with a lack of multidisciplinary and comprehensive courses, resulting in insufficient big engineering thinking and systematic thinking abilities among students. An analysis of the mechanical engineering training programs among the E9 League universities in China reveals that traditional mechanical design and its automation curricula rarely involve interdisciplinary courses. Even when interdisciplinary courses are offered, they lack concrete engineering projects as references and merely introduce some interdisciplinary knowledge. An environment for interdisciplinary and cross-specialty course design and graduation design has not yet been formed. Taking the current mechanical equipment as an example, the research, design, and manufacturing of current mechanical equipment require a high integration of multidisciplinary knowledge such as mechanics, materials, electrical, computer, control, and artificial intelligence. However, the existing discipline-specific training systems are independent of each other, lacking a rapid response mechanism for training engineering and technological innovation talents needed for the transformation and upgrading of the manufacturing industry, and the existing course systems cannot support the cultivation needs of engineering innovation talents under the big engineering perspective. How to examine cognitive rules from the students' perspective and rapidly break through the original academic barriers and professional limitations, how to combine interdisciplinary knowledge systems with engineering practice, and how to build an effective mechanical engineering innovation knowledge system and continuous iteration mechanism are among the core issues that need to be addressed urgently.

3.4. Weakening of Engineering Practice Oriented towards Real Needs

Deep integration of theory and practice is an important approach in new engineering education, but currently, the internship and practical experiences in mechanical engineering are disconnected from industry and societal needs, showing issues of formalism and hollowness. For example, internship practices often involve superficial visits or completing simple operations, with classroom teaching lacking in real cases and practical operations. Surveys have found that taking the production internship of the mechanical design manufacturing and automation major as an example, a production internship lasts four weeks, visiting 8 - 10 factories, involving 10 - 20 workshops or production lines. The main mode of internship involves a technical explainer leading 30 - 50 students through a tour and explanation, making it difficult to deeply integrate theoretical knowledge with engineering practice, only gaining some understanding of the production process. Various course designs (including graduation projects), only a few topics truly achieve organic integration with corporate engineering projects, lacking corporate participation, leading to a disconnect between talent cultivation and corporate needs. Most of the students' innovative practice projects, up to 95%, are based on student's interests, hobbies, or innovative ideas, lacking research into corporate needs, making it difficult for the results of various innovative practice projects by students to be implemented. How to give students opportunities to solve real societal needs and form a sustainable development practice system is an important issue that needs to be addressed urgently.

In response to the above issues, this article focuses on the need for talents driven by national development strategies and industrial transformation, aiming at new technologies, new manufacturing, and new industries, and conducts comprehensive practical exploration around training mechanisms, knowledge systems, and practice platforms under the new engineering perspective for the multidimensional integration cultivation model of outstanding mechanical engineering talents.

4. Exploration and Construction of the Multidimensional Integration Cultivation Model for Outstanding Talents in Mechanical Engineering

The model constructed in this study for the multidimensional integration cultivation of outstanding talents in mechanical engineering starts by addressing the need to support the tackling of critical core technologies in China. It cultivates a "teaching and learning" dual-subject endogenous, progressive training mechanism based on educational and teaching laws; it breaks through with research on cognitive theories, emphasizing the construction of an interdisciplinary mechanical engineering innovation knowledge system; and it starts with the disconnect between engineering education and the cultivation of engineering capabilities to create a sustainable development platform for innovative practice in mechanical engineering. Figure 1 illustrates the multi-dimensional integrated training model for outstanding talents in mechanical engineering.

The model relies on the Party-building brand for value leadership, adheres to the original aspiration of educating people for the Party, consolidates the strengths of the mechanical discipline, and revitalizes the national rejuvenation. By targeting the international forefront of disciplines and focusing on major national needs, it aims to cultivate innovative talents with grand ideals and aspirations, equipped with international perspectives and a sense of mission. This stimulates the intrinsic motivation of both teachers and students as dual subjects; it leads the continuous innovation of teaching content with scientific research and constructs an interdisciplinary mechanical engineering innovation knowledge system through systematic thinking, scientific thinking, and exploratory spirit. With a dual-driving model of product innovation and integration of industry and education, it directly addresses the real needs of enterprises, achieves deep integration of industry and teaching, and builds a sustainable development platform for the innovative practice of cultivating outstanding talents in mechanical engineering.

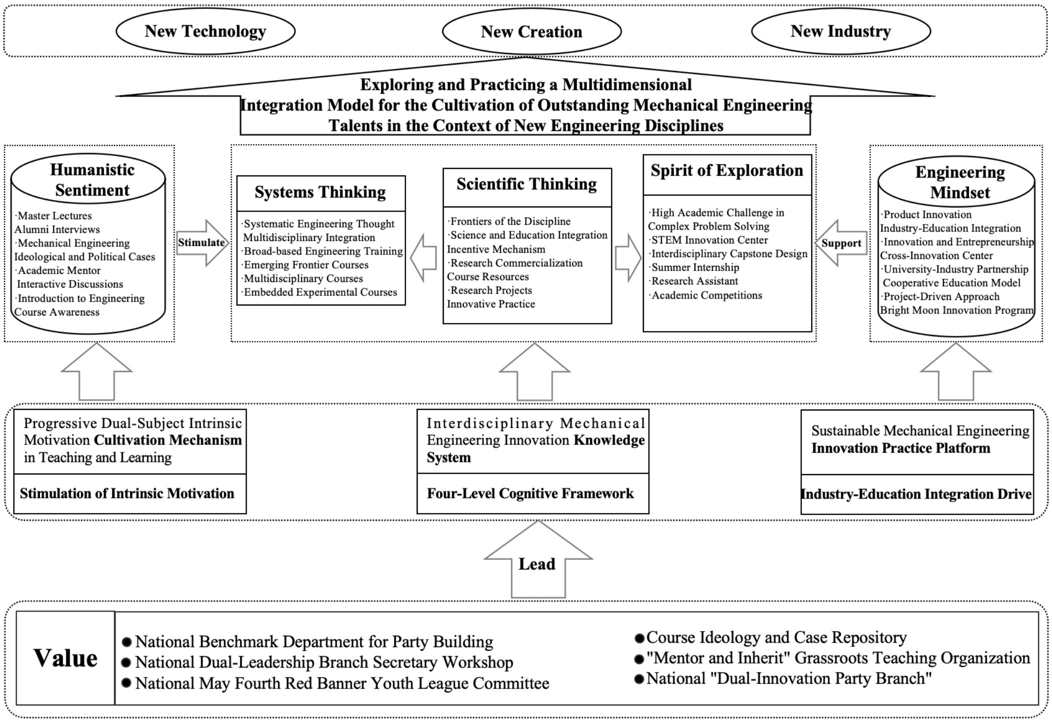

Figure 1. Exploring and practicing a multidimensional integration model for the cultivation of outstanding mechanical engineering talents in the context of new engineering disciplines.

1) The Era Calls for Leading Talent Cultivation: Setting Goals for the Multidimensional Integration Cultivation Model Under the backdrop of "Made in China 2025", mechanical engineering students, as part of the engineering disciplines, must not only master professional knowledge and mechanical engineering practice skills but also embody the craftsmanship spirit and patriotic sentiment of a great nation. China's higher engineering education, situated within the strategy of the great rejuvenation of the Chinese nation and significant global changes, must continuously deepen the reform and innovation of engineering education, uphold moral education, and promote socialist core values. From the "Fudan Consensus" to the "Tianjin Action" and the "Beijing Guide", the construction of new engineering disciplines revolves around the nation's major strategic development needs, aiming to build a strong engineering education nation and support the great national rejuvenation. Based on this understanding, this paper sets the goal of cultivating mechanical engineering professional talents who are adapted to modern technological development and national economic construction needs, with a solid foundation in mathematics and physics, a clear framework of professional knowledge, strong innovation consciousness, a sense of national belonging and an international perspective, and comprehensive development in knowledge, capabilities, and qualities, capable of engaging in scientific research, product development, design manufacturing, and technical economic management in fields such as equipment, manufacturing, transportation, energy, and aerospace.

2) Activating the Intrinsic Motivation of Both "Teaching and Learning" Sub-

jects: Innovative Concepts in the Multidimensional Integration Cultivation Model

Modern educational activities call for a dual return to the consciousness of teachers and students as subjects. By constructing a dual-subject endogenous progressive training mechanism of teachers' "teaching ability-professional ethics-mission commitment" and students' "interest-passion-mission", the intrinsic motivation and potential of both teachers and students are stimulated. For example, the discipline of Chongqing University builds on the achievements of the first-round advanced manufacturing discipline cluster. Centred on mechanical engineering, the university actively explores the concepts and characteristics of emerging engineering disciplines and programs. It seeks new approaches to comprehensive development and talent cultivation under the emerging engineering background, leveraging its strengths as a traditional engineering-focused university. From the perspective of the teacher, relying on national-level teaching and research platforms, through the normalization of multi-disciplinary and mentorship-integrated mechanical foundation and mechanical manufacturing teaching and research rooms, and the characteristic construction of virtual teaching and research rooms transcending time and space, grassroots teaching organizations are restructured. By conducting forefront project research, tackling practical engineering problems, and carrying out project-based teaching demonstrations and engineering case resource construction, overall teaching capabilities are enhanced; through Party-building leadership, tackling difficulties, upholding moral education, and practicing teacher's mission commitment. From the perspective of the student, the main thread is to stimulate students' internal motivation, with engineering introductions, open practices, and science and innovation clubs constructing a system for cultivating student interests; through inquiry-based learning in basic mechanical engineering courses, guided by engineering problems, autonomous learning enthusiasm is ignited; integrating critical and bottleneck issues such as high-end basic parts and industrial mother machines into the ideological education of professional courses, cultivating students' sense of national belonging, industry ideals, and social responsibility, and stimulating their sense of mission and lifelong learning motivation.

3) Reconstructing the Interdisciplinary Knowledge System: Content Upgrades in the Multidimensional Integration Cultivation Model

The educational goal of the mechanical engineering profession is to establish an interconnected conceptual knowledge system that can be applied to problem-solving. Based on advanced cognitive learning theories that learning requires stages of information acquisition, processing, transfer, and epiphany, the article proposes a four-stage realm and cognitive rules for mechanical engineering talent cultivation: "confusion-pursuit-enlightenment-mastery". Based on these cognitive rules, an engineering cognition course group to eliminate engineering confusion, a top-tier course group to solidify students' theoretical foundations, and a series of professional courses to understand the essence of mechanical engineering are constructed; and project-based teaching reforms are implemented simultaneously, introducing multi-disciplinary knowledge driven by problems, effectively integrating theory and practice; and constructing a mechanical engineering innovation knowledge system with a "big engineering perspective" in stages and levels. First, eliminating engineering confusion by implementing an education pathway of "the way of the university", through courses like "Engineering Introduction" and foundational practices, establishing an initial mechanical engineering cognition phase covering all freshmen, where students experience the charm of engineering and eliminate confusion. Second, solidifying professional knowledge by establishing a group of professional basic courses including "Mechanics Principles", integrating science and education, combining industry and education, continuously updating engineering problems and cases in courses, and inquiry-based learning, solidifying students' theoretical framework of mechanical engineering. Third, understanding the essence of mechanical engineering by establishing a professional course group including 10 courses like "Manufacturing Technology", covering all students of the institute with advanced practical projects like engineering projects, scientific research topics, and academic competitions, enhancing the capability to solve real mechanical engineering problems. Fourth, forming a big engineering perspective by establishing a cutting-edge multi-disciplinary cross-module course group covering design, manufacturing, and measurement and control directions, conducting interdisciplinary graduation designs and other cross-practical activities, cultivating systemic thinking with a big engineering perspective, and establishing lifelong learning capabilities.

4) Building an Industry-Education Integration Practice Platform: Process Follow-up in the Multidimensional Integration Cultivation Model

Addressing the vicious cycle where the cultivation of mechanical engineering talents is constrained by insufficient resources, and the new economy lacks new engineering innovative talents, through the multi-party introduction of industry resources, a dual-drive model of "product innovation" and "industry-education integration" is proposed, directly addressing the real needs of enterprises, achieving deep integration of industry and teaching, and forming a sustainable development platform for innovative practice in cultivating outstanding talents in mechanical engineering. First, enhancing innovation and entrepreneurship by breaking traditional disciplinary boundaries, constructing an integrated sequence including "Art and Innovation Laboratory → Manufacturing Laboratory → Engineering Laboratory → Entrepreneurship Community" according to the stages of innovation activities. Second, emphasizing school-enterprise collaboration by establishing a "classroom learning-long-term job internship" school-enterprise joint training model, promoting a dual mentor system between schools and enterprises, and cultivating engineering practice capabilities. Third, striving for product innovation by implementing a project-driven teaching paradigm reform, promoting the docking of student scientific and creative activities with hard-tech product incubation, and achieving effective linkage between student innovation and the innovation chain and industrial chain.

5. Reform Achievements in the Multi-Dimensional Integrated Training of Outstanding Talents in Mechanical Engineering at Chongqing University

The mechanical discipline at Chongqing University has established an interdisciplinary mechanical engineering knowledge system that integrates theory with practice and continuously updates the synergy between scientific research, education, and industry. This system enhances students' scientific thinking, systematic thinking, and engineering skills. Additionally, the university has built a diverse and deeply collaborative innovation practice platform, which strengthens students' innovation and entrepreneurial abilities. As a result, a large number of outstanding mechanical engineering talents with solid theoretical foundations, strong practical skills, and knowledge of cutting-edge advancements have been cultivated.

The multi-dimensional integrated training reform has effectively advanced the coordinated cultivation of outstanding mechanical engineering talents. First, the number of graduates serving key national industries and the western regions of China has significantly increased, with 46% of graduates working in the western region. Second, student development has become more diverse, with many students receiving prestigious national awards, such as the "Star of Social Practice" in Chinese university student social practice, the "National Self-Improvement Star" award, and other honours for excellence in moral and civic achievements. Third, graduates have demonstrated strong international perspectives and innovation capabilities, with a significant increase in employment at famous global companies such as Siemens, ABB, Ford, Volkswagen, General Motors, and Huawei. Additionally, approximately 41% of graduates pursue further studies at top domestic universities (Project 985 institutions), while around 10% continue their education at prestigious overseas universities such as Carnegie Mellon University.

6. Conclusion

Engineering and technological talents are China's most precious resources for creating the future. The article explores and constructs a "training mechanism, knowledge system, practice platform" trinity multidimensional integration cultivation model around the nation's development strategy and industrial transformation needs for talent, aiming to cultivate outstanding mechanical engineering talents with a sense of national belonging, exploratory spirit, scientific thinking, systematic thinking, and engineering capabilities. The cultivation model for outstanding mechanical engineering talents combines the national strategic planning and economic and social development needs, actively aligning with the world's technological forefront in the manufacturing field, the economic main battlefield, targeting industrial mother machines, aerospace, advanced ships, weaponry, new energy transport equipment, and intelligent unmanned equipment. Through value-driven stimulation of learning subjects' intrinsic motivation, following cognitive rules to reconstruct the interdisciplinary knowledge system, and building a sustainable development platform for innovative practice through industry-education integration, the model provides references and lessons for exploring the autonomous cultivation path of outstanding talents in mechanical engineering. Nonetheless, there are still many issues to be addressed in the cultivation of outstanding mechanical engineering talents, including how to solve comprehensive engineering education, emphasize a comprehensive focus on basics, cultivate future engineers with a global vision, resolve the contradictions between general education and professional education, and address the mismatch between talent cultivation and corporate needs. In the future, focusing on new research areas such as intelligent manufacturing and industrial mother machines, further exploration and research will be strengthened around innovative directions for talent cultivation concepts and models.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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