Advances in Educational Technology and Psychology (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/aetp.2024.080701
ISSN 2371-9400 Vol. 8 Num. 7

Research on Modern Machining Theory Reform under the Background of New Manufacturing Industries for Postgraduate Innovative Engineering Competencies

Xue Yang[1,a,*], Chen Jiang[1,b], Hui Ye[1,c]

[1]*School of Mechanical Engineering, University of Shanghai for Science and Technology, Shanghai, 200093, China*

[a]*xueyang@usst.edu.cn*, [b]*jc_bati@163.com*, [c]*yehui513@usst.edu.cn*

[*]*Corresponding author*

Keywords: Modern Machining Theory, Interdisciplinary Integration, Novel Manufacturing, Innovative Engineering Competencies

Abstract: This study focuses on the reform of the Modern Machining Theory curriculum to align with the evolving demands of new manufacturing industries. By emphasizing advanced materials processing, interdisciplinary integration, intelligent manufacturing, and green manufacturing, the curriculum is redesigned to enhance its cutting-edge relevance and practical applicability. Key measures include the adoption of blended learning, project-based learning, and virtual simulation practices to strengthen students' capabilities in intelligent and high-precision machining. Additionally, the evaluation system is restructured to incorporate project-based assessments, interdisciplinary integration, and process-oriented evaluations, encouraging students to develop comprehensive problem-solving skills and innovative thinking. These reforms aim to build an engineering-oriented and innovation-driven postgraduate talent cultivation system capable of addressing the complex challenges of modern manufacturing and research.

1. Introduction

With the transformation and upgrading of global manufacturing and the ongoing advancement of the "New Engineering" initiative, the field of mechanical manufacturing is experiencing a new wave of reform. Against this backdrop, new requirements have been proposed for cultivating postgraduate talents in mechanical engineering, emphasizing "industry-driven needs, engineering practice as the focus, and interdisciplinary integration as the hallmark" to comprehensively enhance the innovation and cutting-edge nature of engineering education[1]. As an essential component of engineering education, reforming the curriculum system for mechanical engineering has become a critical step in achieving this goal[2]. As one of the core courses for cultivating postgraduate talents in mechanical engineering, Modern Machining Theory plays a pivotal role in enabling students to grasp the fundamentals of manufacturing technology and serves as a vital platform for fostering innovative thinking and engineering practice capabilities[3]. However, the traditional course content and teaching methodologies of machining theory are increasingly insufficient to meet the demands of industrial development driven by intelligent, digital, and sustainable manufacturing. In particular, emerging directions such as intelligent manufacturing, micro-nano manufacturing, and green manufacturing necessitate cutting-edge and practical reforms in the course content, teaching models, practical components, and evaluation systems of Modern Machining Theory to align with the advanced requirements of talent cultivation in new manufacturing industries[4].

Currently, the course content of Modern Machining Theory fails to incorporate the core knowledge of cutting-edge fields such as new material processing, interdisciplinary integration, intelligent manufacturing, and green manufacturing. Although innovative teaching methodologies have been explored in other courses, project-based, case-driven, and field-integrated teaching models specific to Modern Machining Theory remain underdeveloped. In practical components, the construction of virtual simulation case libraries lags behind, limiting students' ability to learn complex process dynamics and optimization. Furthermore, the existing evaluation system lacks specificity and has yet to effectively integrate assessments of knowledge application and innovation in Modern Machining Theory, making it difficult to comprehensively evaluate students' ability to connect theoretical knowledge with practical research topics. These challenges (see Fig. 1) underscore the urgent need for systematic reform of Modern Machining Theory to meet the requirements of cultivating high-level engineering talents under the "New Engineering" initiative.

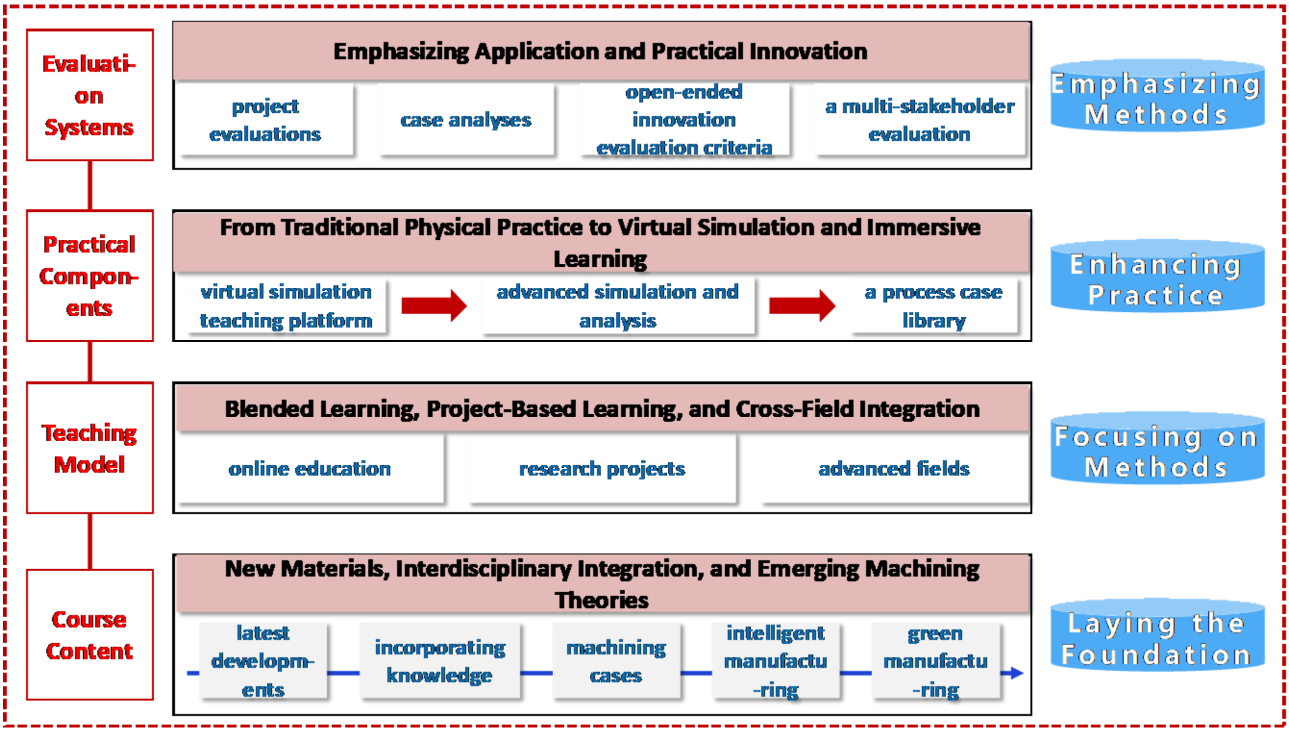

Figure 1: The framework of the study

2. Trends in the Course Reform of Modern Machining Theory

As Modern Machining Theory evolves toward greater intelligence, precision, and sustainability, its course content, teaching methods, practical components, and evaluation systems are exhibiting characteristics of diversification and innovation.

2.1. Course Content Updates Demands

In terms of course content, there is a growing emphasis on integrating new material processing, interdisciplinary knowledge, intelligent manufacturing, virtual manufacturing, and green manufacturing[5]. For instance, the field of new material processing includes research on the properties and processing techniques of composite and nano materials. Interdisciplinary integration necessitates combining mechanical processing with technologies such as artificial intelligence, big data, and microelectronics. Intelligent manufacturing focuses on robotic technology and digitalized processing. Virtual manufacturing enables dynamic simulation of complex processes and the development of process case libraries to provide students with in-depth learning resources. Green manufacturing underscores low-energy processing and sustainable development concepts.

2.2. Requirements for Optimizing Teaching Models

In terms of teaching methods, there is a progressive shift toward blended learning, project-based learning (PBL), and multi-disciplinary integration, emphasizing the enhancement of students' self-directed learning abilities and their capacity to solve engineering problems through project-based scenarios[6]. For instance, in blended learning, students can acquire theoretical knowledge through online learning platforms and engage in in-depth discussions with instructors during classroom sessions. Project-based learning focuses on real-world engineering challenges, such as optimizing machining processes or improving manufacturing equipment, fostering teamwork and innovation skills among students. Cross-filed applications focus on integrating mechanical machining technologies into areas such as intelligent manufacturing, advanced equipment development, semiconductor manufacturing, and optics. Through cross-filed projects, students are encouraged to tackle complex challenges in the manufacturing industry. These transitions in teaching methods effectively stimulate students' interest in learning and enhance both the depth and breadth of their knowledge application.

2.3. Practical Training Transition

In the practical component, there is a transition from traditional physical practices to virtual simulation. Students can utilize virtual environments to simulate complex machining processes, including parameter configuration, process simulation, process optimization, and their application to research projects[7]. For example, with CNC machining simulation software, students can adjust cutting parameters and observe machining outcomes in real time. Through finite element analysis (FEA), they can predict stress distribution, thermal effects, and tool wear to optimize machining processes. Additionally, virtual reality (VR) technology provides immersive operational experiences, such as simulating CNC machine operations, monitoring machining parameters, and addressing abnormal issues. This virtual practice approach reduces costs and risks while enhancing learning efficiency and depth, offering crucial support for students to explore complex manufacturing processes and improve their engineering practice and innovation capabilities.

2.4. Evaluation Systems Development

The evaluation system is gradually evolving towards application-oriented innovation, emphasizing the integration of students' acquired knowledge with other disciplines or real-world projects. This approach not only enhances their practical knowledge application capabilities but also fosters interdisciplinary and cross-domain innovative practices, thereby comprehensively improving their overall competence and research abilities[8]. For example, traditional single-format examinations are being replaced by project-based assessments. Students may be tasked with designing an optimized manufacturing process that integrates principles from materials science, artificial intelligence, and mechanical engineering, or developing a digital simulation system for intelligent manufacturing. Additionally, evaluation content may include assessing students' ability to address complex engineering problems, such as proposing improvements for green manufacturing processes or designing high-efficiency precision machinery. These evaluation methods not only examine students' technical skills and innovative thinking but also encourage them to integrate interdisciplinary knowledge when solving real-world challenges. By adopting an evaluation system that emphasizes the combination of theory and practice, as well as cross-disciplinary collaboration, students are not only motivated to learn but are also better prepared to meet the demands of modern engineering and research.

3. Reform Measures for Modern Machining Theory

Reform measures for modern machining theory are progressively incorporating the distinctive characteristics of new manufacturing industries. These reforms aim to align the curriculum with the evolving demands of intelligent manufacturing, advanced equipment development, semiconductor processing, and green manufacturing. Key initiatives include integrating interdisciplinary knowledge such as materials science, artificial intelligence, and digital simulation into the curriculum to enhance its cutting-edge nature and practical relevance. Additionally, innovative teaching methods such as project-based learning (PBL) and virtual simulation are being adopted to encourage students to solve real-world manufacturing challenges through cross-disciplinary collaboration. By emphasizing industry-oriented applications and advanced technologies, these reform measures not only modernize the curriculum but also cultivate innovative engineering talents capable of addressing the complex needs of contemporary and future manufacturing industries.

3.1. Focusing on New Materials, Interdisciplinary Integration, and Emerging Machining Theories

By introducing new modules on advanced materials processing, incorporating interdisciplinary content, and integrating emerging machining theories, the curriculum aims to comprehensively enhance its cutting-edge relevance and practicality, aligning with the demands of future manufacturing industries.

To expand the materials processing module, new content is added on the characteristics and processing techniques of advanced materials such as composites and nanomaterials, emphasizing the impact of material properties on machining methods. This helps students understand the latest developments and technological applications in the field of advanced materials. Interdisciplinary content is strengthened by incorporating knowledge from fields such as artificial intelligence, big data, and microelectronics. Cross-domain machining cases are developed, such as using intelligent algorithms to optimize process parameters or addressing the precision machining of microelectronic devices, equipping students with the ability to solve complex, interdisciplinary problems. Focusing on intelligent manufacturing technologies, the curriculum introduces robotic machining, digital production lines, and the industrial Internet of Things. Case studies are designed around intelligent machine tool programming and monitoring, familiarizing students with advanced machining techniques in smart manufacturing environments. Green manufacturing concepts are also integrated into the curriculum. New content is added on low-energy machining processes, material recycling, and waste management, guiding students to focus on environmentally friendly machining technologies and sustainable manufacturing strategies.

3.2. Blended Learning, Project-Based Learning, and Cross-Field Integration

By introducing blended learning, implementing project-based learning (PBL), and promoting cross-field integration, innovative measures of teaching models are being adopted to comprehensively optimize the teaching model of Modern Machining Theory. These efforts aim to enhance the curriculum's adaptability to industrial demands, effectively improve students' learning engagement, and strengthen their ability to solve complex engineering problems.

Blended learning combines online education with in-class interactions, where students acquire foundational theoretical knowledge through online platforms and engage in in-depth discussions and practical applications during class. For instance, online resources can facilitate pre-class preparation, while in-class activities focus on problem-based discussions and hands-on practice. Project-based learning (PBL) is implemented by aligning course content with real research projects. Students are tasked with practical assignments such as developing machining process models, optimizing machining techniques, or improving existing manufacturing equipment. These tasks allow students to enhance their collaborative skills and innovative thinking in a team setting, bridging the gap between theory and practice. Multi-field integration is encouraged by incorporating interdisciplinary projects into the teaching process. This involves combining mechanical machining theory with advanced fields such as intelligent manufacturing, robotics, semiconductor manufacturing, and optical design. Through cross-domain project analysis and real-world problem-solving, students develop the skills to address complex manufacturing challenges. Scenario-based teaching is also introduced, simulating real-world industrial problems and designing teaching cases that align closely with industry needs. For example, tasks such as machining monitoring using digital twins or process optimization for intelligent devices are incorporated, enhancing students' ability to apply their knowledge in authentic industrial contexts.

3.3. From Traditional Physical Practice to Virtual Simulation and Immersive Learning

By building virtual simulation platforms, introducing advanced simulation tools, and developing immersive practice modules, the efficiency and flexibility of practical training are comprehensively optimized. These measures not only reduce costs and risks but also provide students with opportunities to explore complex manufacturing processes in depth, significantly enhancing their engineering practice skills and innovative competencies.

A virtual simulation teaching platform is established using CNC machining simulation software and virtual laboratories, offering students opportunities to simulate machining processes and adjust parameters. For example, through a CNC simulation platform, students can modify cutting parameters and observe machining results in real time, fostering an intuitive understanding of process optimization. Advanced simulation and analysis tools are introduced, incorporating finite element analysis (FEA) and MATLAB programming into practical teaching. These tools help students predict stress distribution, thermal effects, and tool wear during machining processes, enabling them to optimize machining plans and solve real-world problems. A virtual reality (VR) practice platform is employed, leveraging VR technology to simulate the operation of complex machining equipment. Students can practice tasks such as starting CNC machines, monitoring machining parameters, and handling abnormalities, improving their operational and problem-solving skills through immersive practice. A process case library and practical tasks are developed by collecting and organizing simulation cases of complex processes and designing practice tasks aligned with real industrial needs. This enables students to conduct in-depth analysis and validate solutions through simulation cases. A hybrid practice model combining virtual and physical practices is promoted. Students first familiarize themselves with machining processes in a virtual environment and then transition to physical equipment for hands-on experience. This approach enhances their adaptability to real-world engineering scenarios.

3.4. Emphasizing Application and Practical Innovation

By introducing project-based assessment methods, emphasizing the evaluation of interdisciplinary integration skills, and increasing the weight of process-oriented assessments, the evaluation system of Modern Machining Theory is comprehensively optimized. This approach strengthens the integration of knowledge application and practical innovation, effectively motivating students to enhance their interdisciplinary capabilities while fully improving their comprehensive qualities and innovation levels to meet the demands of modern manufacturing and research.

Project-based assessment methods are introduced by combining traditional exams with project evaluations. Interdisciplinary project tasks are designed, such as requiring students to develop optimized machining processes integrating artificial intelligence and mechanical processing or to design strategies for implementing green manufacturing technologies, comprehensively assessing their practical application skills. The evaluation emphasizes interdisciplinary integration by including multi-domain requirements in the assessment content. For instance, case analyses are used to evaluate how students combine materials science, digital technology, and machining theory to solve complex engineering problems, cultivating their cross-disciplinary innovation capabilities. The weight of process-oriented assessments is increased, focusing on students' engagement, project progress, and laboratory reports during the course. This approach not only evaluates final outcomes but also values students' thought processes and growth while solving problems. Open-ended innovation evaluation criteria are established to encourage students to propose original solutions or improve existing processes. Examples include optimizing tool designs, enhancing machining workflows, or developing virtual simulation tools, extending the evaluation scope to cover technological innovation and engineering practices. A multi-stakeholder evaluation model is adopted, incorporating teacher-student interaction, self-assessment, and peer evaluation into a comprehensive evaluation system. This multi-dimensional and multi-perspective approach assesses students' overall capabilities while fostering teamwork and self-reflection skills.

4. Conclusions

The reform of the Modern Machining Theory curriculum focuses on optimizing course content, teaching methods, practical components, and evaluation systems, emphasizing features such as advanced materials processing, interdisciplinary integration, intelligent manufacturing, and green manufacturing. Through blended learning, project-based learning, and virtual simulation practices, the reform aims to strengthen students' capabilities in intelligent and high-precision machining. By integrating project evaluation and innovation assessment, it seeks to comprehensively enhance students' practical innovation skills and cross-disciplinary competencies, ultimately building an engineering-oriented and innovation-driven postgraduate talent cultivation system that meets the demands of future manufacturing industries.

Acknowledgements

This work was supported by University of Shanghai for Science and Technology Outstanding Engineer "Industry-Education Integration Community" Construction Project, University of Shanghai for Science and Technology Graduate Teaching Achievement Award Cultivation Project, and University of Shanghai for Science and Technology School-Enterprise Co-Developed Advanced Courses for Outstanding Engineers.

References

[1] Wang X. Research on the Teaching Mode Innovation of Computer Majors Under the Background of Industry and Education Integration[J]. Journal of Contemporary Educational Research, 2024, 8(6):77-82.

[2] Xu H. Innovation Research on PBL Teaching Model for International Trade Talent Training under the Background of Industry-Education Integration[J]. International Journal of New Developments in Education, 2024, 6(8):113-118.

[3] Pei S. Research on Industry-Education Integration Model of Vocational Education Applying Automatic Coding[J]. Applied Mathematics and Nonlinear Sciences, 2024, 9(1): 1-17.

[4] Lv Y, Wang G, Zhang H, Xin Q. Research on Teaching Reform of Mechanical Drawing Course for Applied Undergraduate Robot Engineering Major[J]. Curriculum and Teaching Methodology, 2023, 6(20): 132-139.

[5] Patange G, Jobaliya J. Scope for problem solving in industrial engineering and management subject curriculum reform for mechanical engineers to leverage the current and upcoming situations[C]//PMaterials Today: Proceedings. 2023: 853-857.

[6] Liu D, Sun Y. Innovation Transformation and Industry Education Integration: A Study on the Integration Path of Guangxi Zhuang's Intangible Cultural Heritage and Master of Arts Education in China[J]. Journal of Contemporary Educational Research, 2024, 8(4): 86-91.

[7] Yu C, Yin S, Bao Y, Tian T. Exploration of professional practice teaching reform in local application-oriented universities—Taking mechanical engineering as an example[C]// SHS Web of Conferences. 2023, 157, 02020. https://doi.org/10.1051/shsconf/202315702020

[8] Ao H, Zhang H, Zhang J. "Teaching Reform and Practice of Strengthening Engineering Education in Mechanical Engineering Specialty." 2022 International Conference on Engineering Education and Information Technology (EEIT) (2022): 45-48.