Exploration on the Integration of Engineering Training and Graduation Design in Practical Teaching Reform under the Background of Emerging Engineering Education

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Abstract: This paper addresses issues observed in undergraduate capstone projects within the context of Emerging Engineering Education—such as topics detached from practical applications and insufficient hands-on student experience—by proposing a practical teaching reform model that deeply integrates engineering training with graduation project work. A three-phase progressive cultivation system, consisting of "basic training–comprehensive practice–capstone project", was constructed, and a fully project-driven teaching mechanism implemented, with project topics derived from real-world sources including enterprise technical upgrades, scientific research projects, and academic competitions. The reform emphasizes a closed-loop iterative process of "design–processing–feedback–redesign", enabling students to undergo complete workflow training from concept to physical prototype. Furthermore, a collaborative guidance team comprising on-campus theoretical advisors, practical training instructors, and industry-based mentors was formed. A multi-dimensional evaluation system prioritising process and practical competency assessment has been established, leading to a marked enhancement in students' engineering practical abilities and innovative capacity.

Keywords: Capstone Project; Engineering Training; Assessment System; Engineering Practice

1. Introduction

In the context of Emerging Engineering Education development, engineering education is actively aligning with industrial transformation and technological frontiers, emphasizing the deep integration of interdisciplinary collaboration, innovation capability, and practical skills [1]. The undergraduate capstone project serves as a culminating practical teaching activity implemented in the final stage of the educational process. It represents a comprehensive design exercise in which students apply acquired theoretical knowledge and technical skills to solve real-world problems after completing all course requirements [2]. However, the traditional capstone project model exhibits significant shortcomings: many students lack engineering application experience and possess only a superficial understanding of the design topics, often uncertain about how to proceed. As a result, designed components may not be manufacturable; manufacturable parts may not assemble properly; and assembled systems may fail to operate correctly. This lack of engineering practice validation in capstone projects hinders their intended purpose of consolidating knowledge and professional skills, as well as enhancing students' independent thinking, innovative capacity, and practical competence [3].

Engineering training, as a critical component in cultivating students' practical abilities and engineering awareness, can effectively address the aforementioned issues through organic integration with capstone projects. In recent years, higher education institutions have been actively exploring reforms in engineering training pedagogy [4]. For example, the Engineering Training Center at Hebei University of Science and Technology has established a practical teaching model characterized by "skill training + comprehensive training" to enhance students' ability to integrate and apply knowledge holistically [5]. These explorations provide valuable experience for the integration of capstone projects and engineering training.

2. Overview of Engineering Training Practical Teaching

Engineering training is a practical foundational course for engineering students in mechanical disciplines, aimed at systematically imparting fundamental knowledge and core skills in mechanical manufacturing [6]. It serves as an indispensable component in cultivating students' engineering practical abilities. The course integrates theoretical teaching and hands-on training to help students comprehensively understand mechanical manufacturing processes, familiarize themselves with production techniques and standards, and master the essential safety procedures for operating various processing equipment and tools. Students will learn the basic properties and applications of commonly used engineering materials, acquire traditional metal-cutting techniques such as fitting, turning, milling, grinding, and planing, gain exposure to precision machining and component assembly technologies, and receive an introductory understanding of advanced manufacturing technologies including CNC machining, non-traditional machining, computer-aided design/manufacturing (CAD/CAM), and 3D printing. Through a teaching model that emphasizes "learning by doing and doing while learning," guided by the craftsman spirit, the course focuses on developing students' rigorous and meticulous work attitude, fostering professional dedication, enhancing labor awareness and discipline, promoting the integration of theory with practice, and striving to achieve the educational goal of combining moral and technical cultivation for comprehensive development [7].

3. Existing Problems in the Practical Model of Undergraduate Capstone Projects

As a crucial comprehensive practical teaching component in higher education, the undergraduate capstone project aims to cultivate students' ability to integrate and apply theoretical knowledge and technical skills to solve complex engineering problems, while initially fostering innovative awareness and a rigorous work ethic. However, its current implementation has revealed a series of urgent issues that seriously hinder the improvement of talent training quality [8].

3.1 Uneven Topic Quality and Detachment from Engineering Practice

Many capstone project topics are repetitive and outdated, with some even being reused over multiple years. Topics often originate from instructors' hypothetical scenarios or minor modifications of existing subjects, lacking authentic engineering contexts and practical application value. Some topics are excessively broad, making them difficult for students to manage effectively, while others are too narrow to achieve the goal of comprehensive training. This results in a lack of student engagement, perfunctory efforts, and design outcomes that are severely disconnected from real-world industry needs.

3.2 Imbalance between Supply and Demand of Educational Resources and Inadequate Guidance

Following the expansion of college enrollment, the issue of imbalanced faculty-student ratios has become prominent, with a single instructor often required to guide excessive number of students, diluting their attention and effort. Moreover, many teachers, particularly young faculty members, lack practical engineering experience themselves, resulting in guidance that often remains theoretical and fails to provide students with effective practical insights. However, investment in teaching resources has lagged relatively behind, leading to resource constraints for students in areas such as literature access, experimental equipment, computer and professional software usage, which constrains the depth and quality of design work.

3.3 Insufficient Student Engagement and Misconceptions

The capstone project is primarily concentrated in the eighth semester, a critical period when students are typically preoccupied with job hunting and postgraduate entrance examination interviews, making divided attention extremely common. Many students lack sufficient awareness of the importance of the capstone project, viewing it merely as a "final formality" required for obtaining their degree rather than a valuable opportunity to enhance their competencies. Driven by a utilitarian mindset, some students adopt a passive attitude, and may even engage in academic misconduct such as plagiarism, patchwriting, or outsourcing their work. Although most universities have established regulations and guidelines for capstone projects, process management is often lax and enforcement is weak. Intermediate inspections, daily attendance checks, and other supervisory steps are frequently compromised due to conflicts with students' job searches, postgraduate exam preparations, and graduation internships. Additionally, instructors often provide insufficient daily supervision and formative assessment, resulting in a common pattern of negligence in the early stages and last-minute rushed efforts toward the end. Furthermore, objective factors such as remote campus locations exacerbate difficulties in teacher-student communication and interaction.

3.4 Lack of Scientific Rigor in the Assessment and Evaluation System

The current evaluation approach prioritizes outcomes over process, and emphasizes drawings and documentation at the expense of practical abilities. Assessment relies heavily on the final thesis and defense performance, with insufficient attention paid to students' learning attitude, level of effort, innovative thinking, and problem-solving capabilities during the design process. The defense session is sometimes conducted in a perfunctory manner, with highly subjective grading criteria that compromise the fairness of evaluation and fail to motivate students effectively.

In summary, undergraduate capstone projects face severe challenges in topic selection, resource allocation, process management, student engagement, and evaluation systems. These issues hinder the capstone project from fully fulfilling its intended function of cultivating comprehensive practical and innovative capabilities. Substantially deepening the reform of the capstone project model—by promoting deeper industry-academia-research collaboration, strengthening the dual-supervisor guidance system, implementing a physical artifact-oriented approach, and enhancing process supervision and diversified assessment—is of great significance for improving the quality of applied undergraduate talent cultivation.

4. Integration of Engineering Training and Capstone Project: A Practical Reform Initiative

The integration of engineering training and capstone project is a systematic solution proposed to address deep-seated issues in traditional engineering education, such as fragmented practical teaching components, disconnection between theory and practice, and separation of industry and academia. This reform establishes a progressive cultivation system comprising three organically linked stages—"basic training, comprehensive practice, and capstone project"—breaking down traditional course barriers and achieving continuity and advancement in engineering capability development.

During the basic training stage, the focus is on developing students' equipment operation skills and awareness of engineering safety standards. The comprehensive practice stage employs a project-based training model, requiring students to complete the design and processing of structural and assembly parts, as well as integrated tasks such as device assembly, debugging, and installation. The capstone project stage, building on the preceding training, involves a 16-week in-depth practical period to achieve comprehensive enhancement of engineering capabilities.

4.1 Construction of Engineering Application-Oriented Topic Selection Mechanism

The undergraduate capstone project serves as a core component in engineering talent cultivation, and its deepening reform aims to strengthen practical teaching effectiveness and tangibly enhance students' ability to solve complex engineering problems [9]. The core of this reform lies in implementing a fully project-driven teaching approach, organically integrating the capstone project with the undergraduate internship to achieve both content deepening and process restructuring. The traditional internship, which was conventionally concentrated in the eighth semester, is now fully integrated into the capstone project process. This integration extends the capstone project beyond the final semester's theoretical derivation and thesis writing, forward-expanding to cover the entire internship period, thereby forming a cross-semester, high-intensity, and unified comprehensive training process. In terms of topic selection, adherence to real-world engineering applications is emphasized: 30% of topics originate from enterprise technical renovation needs, 30% from transformed research projects, 20% from disciplinary competition projects, and 20% from student-initiated innovative topics, ensuring that each task possesses a clear engineering background and practical application value.

4.2 Construction of a Capstone Project Model Centered on Machining-Feedback-Driven Design Optimization

During the implementation of the capstone project, we emphasize that students should not remain solely at the theoretical cognition and basic operation levels, but must fully participate in the entire practical process—from product design, process planning, and machining to testing and validation. In this process, students enter the engineering training center and operate machining equipment such as lathes, milling machines, CNC devices, and 3D printers to transform design drawings into physical parts. Particularly importantly, the machining phase profoundly informs design optimization: students often discover in practice that certain structures are difficult to manufacture, that assembly interferences exist, or that strength is insufficient, leading them to proactively revise design schemes, adjust material selections, or optimize process parameters. This achieves a closed-loop iteration of “design–processing–feedback–redesign.” This mechanism fully reflects the real-world engineering logic of mutual promotion and continuous integration between design and manufacturing.

By incorporating the workplace experience and technical training originally required in the graduation internship, the capstone project process genuinely embodies “learning by doing and doing while learning,” enabling students to systematically develop comprehensive problem-solving skills in an authentic engineering context. Simultaneously, it effectively avoids the problems of traditional capstone projects being detached from practice and internships becoming mere formalities. Ultimately, a practice-driven, competency-oriented integrated training system is constructed.

4.3 Formation of the Teaching Team

The capstone project supervision team fully implements a "dual-supervisor model," consisting of both academic advisors and industrial engineers, with the actual participation rate of industry mentors strictly maintained at no less than 50%. In terms of faculty development, the academic advisor team is further refined into theoretical advisors and practical training instructors: theoretical advisors are primarily responsible for foundational disciplinary knowledge, design principles, and academic standard guidance; practical training instructors, relying on platforms such as the engineering training center, guide students in machining, process implementation, and prototype debugging, emphasizing the concrete application and transformation of theory into practice. Industry mentors focus on product-oriented guidance, providing technical support from the production front line and feasibility assessments of manufacturing processes, thereby promoting the iteration of designs toward manufacturable, assemblable, and testable product forms. The three types of supervisors collaborate throughout the process, enabling a complete cycle in which "theoretical guidance informs practice, while practice validates and optimizes theory." This effectively ensures that the capstone project possesses both solid theoretical depth and significant engineering practicality and technical advancedness [10].

4.4 Development of the Assessment System

In order to comprehensively and objectively evaluate students' comprehensive capabilities throughout the entire capstone project process and ensure the achievement of the four core objectives—"theoretical understanding, design capability, manufacturing skills, and practical application"—a diversified assessment scheme has been specifically formulated [11]. This system emphasizes the integration of process evaluation and summative evaluation, as well as the combination of academic and industrial assessment, breaking away from the traditional over-reliance on a single path that prioritizes thesis writing over practical implementation [12]. The comprehensive assessment indicator system is shown in table 1.

Table 1. Comprehensive Assessment Indicator System

Assessment dimensions	Assessment stage	Assessment content and indicators	Assessment subject	Weight
Design ability	Initiation and mid-term	The sufficiency of literature research, the feasibility of technical routes, and the correctness and depth of the application of theoretical tools	On-campus theoretical supervisor	15%

		The innovation of the design scheme, the standardization of the drawings, the rationality of the technical parameters, and the accuracy of the calculations	On-campus theoretical supervisor	15%
Practical ability	Manufacturing and Testing	The rationality of process planning and the accuracy of material and equipment selection	On-campus practical training supervisor	10%
		The ability to operate equipment, the quality of parts processing, and the skills for equipment debugging	On-campus practical training supervisor	15%
		The scientific nature of the testing methods, the completeness of data records, and the objectivity of result analysis	On-campus practical training supervisor / theoretical supervisor	5%
Engineering value	Defense and final evaluation	The practicality, reliability and social value of the project outcomes	Enterprise mentor	15%
		Process performance, defense statement and problem presentation	Thesis defense committee	15%
Innovativeness	The entire process	It is innovative in terms of theory, design, process and application	Thesis defense committee	10%

5. Concluding Remarks

The practical reform has significantly strengthened the engineering and application orientation of the capstone project, highlighting the cultivation feature of industry-education integration. It is not only an innovation in teaching form but also an upgrade in educational philosophy: through real-world project-driven tasks, the dual-supervisor collaborative mechanism, and the full-cycle practice of “design–processing–feedback,” students’ capstone outcomes not only meet academic standards but also demonstrate solid engineering practical abilities and strong professional adaptability. This integrated model effectively addresses the core issues of traditional capstone projects being disconnected from engineering practice and students lacking practical skills. It establishes a unified cultivation path characterized by “three-phase progression, multi-agent collaboration, and closed-loop iteration,” comprehensively enhancing students’ engineering literacy and innovation capacity. This practice provides a successful example for cultivating applied talents in the context of emerging engineering education, demonstrating significant demonstrative and promotional value for deepening industry-education integration and advancing the connotative development of engineering education.

Acknowledgments

This paper is supported by the Metal Cutting and Machine Tools under the Background of Emerging Engineering Education (No. 2022JXYJ16) and the Metal Cutting and Machine Tools (No. 2023XQZYK35).

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