Engineering Education Review

PRACTICE

How to cultivate interdisciplinary and comprehensive practical abilities of engineering students—a case study of innovative design and advanced manufacturing center at South University of Science and Technology

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ABSTRACT

To enhance the innovation and engineering competence of undergraduate students, this study proposes a modular and progressive practical curriculum system based on three platforms: innovative design, advanced manufacturing, and automation/robotics/artificial intelligence. Diverse practical activities—including scientific research practice, engineering projects, industrial internships, competitions, innovation/entrepreneurship programs, and integrated design tasks—are designed to align with teaching objectives. To enhance effectiveness, a quality assurance mechanism spanning the entire project lifecycle is implemented. This includes establishing a diverse practice project library, standardizing credit certification procedures, assembling interdisciplinary mentorship teams, and adopting process-oriented evaluation that emphasizes both explicit outcomes (*e.g.*, prototypes, patents) and implicit competencies (*e.g.*, problem-solving, teamwork). Furthermore, a school-enterprise collaboration platform is established to integrate industry challenges into curricula, enabling students to address real-world engineering issues. Through the deep integration of "production-learning-research-application", this framework bridges education, talent development, innovation, and industrial chains, thereby comprehensively improving students' creativity, practical skills, and capacity to solve complex engineering problems.

Key words: engineering education, engineering competence, practical teaching, university-industry partnership, case study

INTRODUCTION

Currently, digital technologies exemplified by Generative Artificial Intelligence (GenAI) are continuously challenging traditional models of higher engineering education, triggering a new round of reform and innovation in this field on a global scale. Even with the advent of Artificial Intelligence (AI), humans should not relinquish thinking and experiencing; it is akin to the fact that humans still need to learn to walk even after the invention of the automobile. AI cannot replace human creativity, which is the core aspect that education in the age of intelligence should emphasize and reinforce. In applied sciences like engineering, theory and practice

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should be developed in harmony. This means that engineering education at universities should be as innovative as the practice in companies and other institutions (Kretschmann, 2024). In the era of AI, higher engineering education places greater emphasis on the deep integration of technological innovation and industrial innovation, and also pays more attention to cultivating students' creativity and interdisciplinary comprehensive abilities.

Amidst the accelerated pace of a new round of technological revolution and industrial transformation worldwide, China urgently needs to cultivate a large number of high-quality engineering and technical talents to drive economic quality improvement, efficiency enhancement, and upgrading. Therefore, China has a large-scale higher engineering education system, which supports its position as the world's largest manufacturing country and its emerging status as a leading manufacturing power. According to statistics from the Ministry of Education, 92% of universities in China offer engineering programs, with a total of 19,447 engineering majors across the country's regular undergraduate institutions, enrolling over 5.5 million students (Cao, 2022). Facilitating practical training for a large cohort of engineering students at the cutting edge of engineering projects during their undergraduate years constitutes a substantial organizational and logistical challenge. Consequently, Chinese universities have long established engineering training centers and other practical teaching facilities on campus to foster the engineering practical skills and innovative capabilities of undergraduate students. In order to enhance students' innovation and engineering practical abilities, Chinese universities have been reforming and innovating the teaching systems and models of engineering training practice. Tsinghua University, relying on the Basic Industry Training Center, has explored a new educational model that integrates the maker spirit into teaching practice. Huazhong University of Science and Technology, relying on the Intelligent Manufacturing Engineering Innovation Practice Platform, has constructed an intelligent manufacturing practice teaching system aimed at cultivating a broad engineering perspective and proposed the concept of "practice-driven innovation" for cultivating intelligent manufacturing innovative talents (Wang *et al.*, 2022). Zhejiang University's Engineering Training Center has established a three-tier innovation system of engineering training that integrates innovative elements, general innovation training projects, and project-driven innovation activities (Qian *et al.*, 2022). Northeastern University's Engineering Training Center has built a practical teaching system called the "Three Modes and One Guarantee" focusing on basic practical training, cross-disciplinary innovation exploration, and project integration enhancement (Liu *et al.*, 2022). Beijing Institute of Technology's Engineering Training Center has constructed a four-tier engineering training practice teaching system consisting of engineering cognitive practice, engineering basic practice, engineering comprehensive practice, and innovation and entrepreneurship practice (Fu *et al.*, 2020). South China University of Technology's Engineering Training Center has built a multi-dimensional and multi-level engineering training curriculum system (Yan *et al.*, 2021). In these engineering training centers, students can engage in practical processes, enabling them to promptly acquire professional knowledge, innovative methodologies, and new competencies pertinent to the tasks at hand. Additionally, they can experience the dynamic updating of the knowledge system and industrial innovation (Hu & Song, 2025).

Internationally, universities are also actively exploring new methods to cultivate the interdisciplinary and comprehensive practical abilities of engineering students, in order to address the challenges brought by the era of AI. For example, with the creation of digital twins by combining a design model with the use-phase data of a product or a system, Tampere University of Technology introduces a versatile learning environment focusing on a Flexible Manufacturing System training center, which is based on the learning environment consisting of a physical training system and its digital twin (Toivonen et al., 2018). Laboratory of Manufacturing Systems & Automation of University of Patras brings up the concept of the Teaching Factory (TF) Network, namely a large-scale implementation of the TF paradigm within a network of academic and industrial organizations, extending the potential of launching training collaborations to a large network of manufacturing companies and universities and maximizing the relevant impact and accelerating a paradigm shift in manufacturing education and training (Mavrikios et al., 2019). Norwegian University of Science and Technology discusses the possibility of transferring the knowledge of learning factories to manufacturing education and developing adaptable evaluation tools for educational contexts. Moreover, challenges in designing an evaluation tool for debriefing are discussed (Tvenge & Ogorodnyk, 2018).

The evolving demands of the modern industry, particularly in the era of AI, raise a critical question for engineering education: How can universities effectively cultivate the interdisciplinary and comprehensive practical abilities of their students? This paper seeks to address this question by presenting a case study of a successful initiative at Southern University of Science and Technology. Through an in-depth analysis of this case, we aim to provide strategic and policy implications for policymakers and educational practitioners.

CASE STUDY: THE INNOVATIVE DESIGN AND ADVANCED MANUFACTURING CENTER OF SUSTECH

The South University of Science and Technology (SUSTech) represents a new-model research university that has garnered significant attention in China. Despite its relatively short history of 15 years, SUSTech has rapidly ascended to the ranks of the world's top universities. As a new-model research university, it is committed to cultivating top-tier innovative talents by emphasizing fundamental research, cutting-edge scientific and technological advancements, and serving the development of national strategic emerging industries and future industries. In response to the prominent issues faced in the cultivation of innovative talents, SUSTech focuses on frontier, revolutionary, and disruptive technologies expected to emerge over the next 10 to 15 years. The university aims to break away from traditional conventions, constraints, and institutional barriers, thereby fostering forward-thinking talent capable of driving future development.

As part of its mission of cultivating top-notch innovative talents, SUSTech established the "Innovation Design and Advanced Manufacturing Center (referred to as the Center below)" related to mechanical engineering disciplines within the university in 2016. The Center is supported by three major platforms: the "Advanced Manufacturing Platform", the "Innovation Design Platform" and the "Automatic Control, Robotics, and Artificial Intelligence Technology Platform".

Since its inception, the Center has set three main objectives. The first is to support undergraduate teaching by providing support for daily experimental teaching and practical activities in disciplines such as mechanical engineering, robotics engineering, new energy science and engineering, mechanics and aerospace engineering, materials science and engineering, and biomedical engineering. The Center oversees experimental and practical teaching for a wide range of course platforms, including the Science and Engineering Platform Courses, Innovation Design Courses, Advanced Manufacturing Courses, Control and Robotics Courses, Energy Courses, and Comprehensive Practice Courses.

The second objective is to promote undergraduate scientific research by organizing a range of innovation-focused extracurricular activities. These activities are built around emerging themes such as "new energy", "intelligent manufacturing", and "micro-nano robotics". They serve to attract participation from industry stakeholders, introduce cutting-edge academic and industry topics, and offer substantial guidance for student research endeavors.

The third objective is to establish a stronger links with the industry by introducing real world topics and project into the curriculum. This enables undergraduates to engage with the forefront of technological development and better understand industry dynamics. These efforts ensure that student projects remain closely aligned with industry needs and address the most current and advanced challenges.

Development of a modular, hierarchical, and customizable practical course system

The Center is supported by three major modules: the Innovation Design Platform, the Advanced Manufacturing Platform, and the Automatic Control, Robotics, and AI Technology Platform. These platforms collectively undertake the crucial role of supporting practical teaching for relevant undergraduate programs, with the principal courses by each platform as shown in Figure 1. Based on the three primary practical platforms, a capability-progressive practical course system has been established, comprising three successive levels of practical activities: cognitive, skills and guidance, and autonomy. (Wei *et al*., 2023).

At the cognitive level of practical activities, primarily depend on course-based practical components, students are developed in their understanding of the profession and stimulated in their innovation awareness. At the skills and guidance level of practical activities, mainly relying on the practical activities in the courses and specialized practical courses, students are nurtured in their professional qualities and practical hands-on abilities. At the autonomy level, which relies mainly relying on professional practice, innovation and entrepreneurship practice, comprehensive engineering training, graduation design, academic competitions, undergraduate research projects, *etc*., students are further developed in their capacity for interdisciplinary and cross-disciplinary integration, innovation and entrepreneurship, professional ethics, and social responsibility.

Implementing a quality assurance mechanism throughout the entire process of the integrated project

For the three levels of practical activities mentioned previously, the first two levels-cognitive practice and guided skills practice—mostly consist of experiments or practical activities within courses, with relatively fixed timeframes, in these cases, instructors can have comprehensive control over the quality of these experiments or activities. For the third level, the advanced autonomous practice, since practical credits are awarded based on the completion of practical projects by students, the sources of projects for credit recognition are diverse, and the

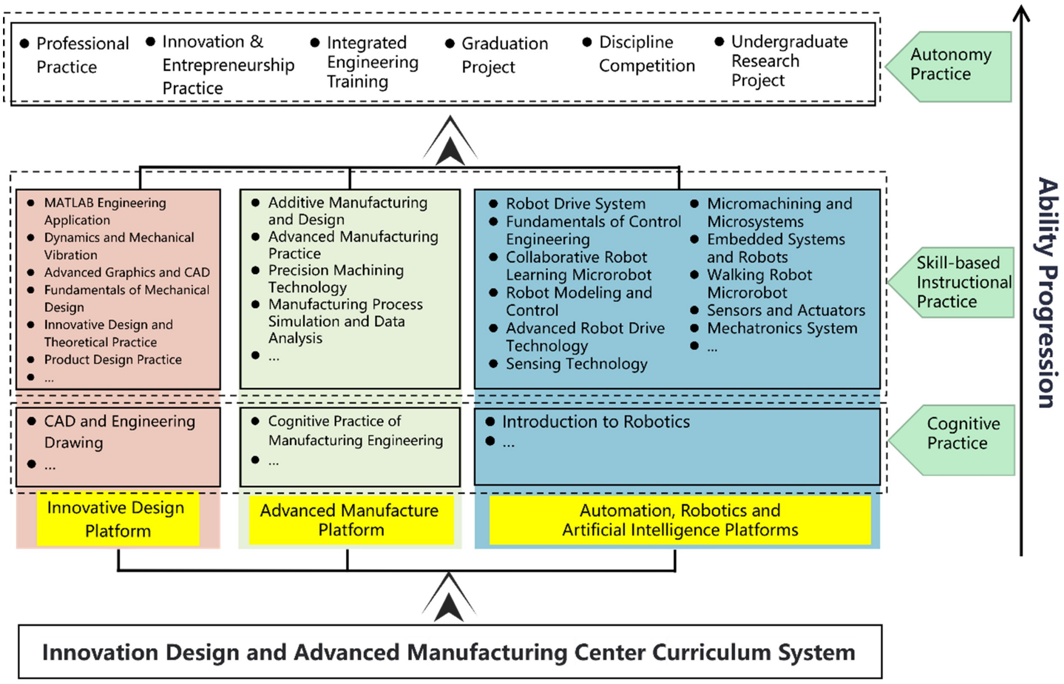

Figure 1. Curriculum system of Innovation Design and Advanced Manufacturing Center.

timing of practical activities is uncertain. Therefore, establishing a comprehensive quality assurance mechanism for the entire process of projects, including project selection, project execution, and project output, is critically importance for enhancing the effectiveness of practical activities. The structure of the quality assurance mechanism covering the entire process of integrated projects is illustrated in Figure 2.

During the initial stage of the project, the project topic is determined, with the sources varying widely. These include real-world practical projects provided by companies based on the current industry demands, student-initiated university innovation and entrepreneurship projects, "climbing" programs, research projects from professor-led research groups focusing on cutting-edge disciplines, and themed projects such as those focus on "new energy" and "bionic robots" conducted regularly. Students are free to select projects that align with their interest for practical implementation, and upon completion of the project, they can obtain practical credits based on relevant requirements.

In the execution stage, a robust project supervision system is implemented. For company projects, a dual mentor system is used, consisting of an on-campus mentor and a company mentor, who jointly oversee the project's innovation, relevance to the profession, and feasibility. Additionally, a professional support team, including lab technicians, engineers, and teaching assistants, is provided to offer technical support for project implementation. Detailed guidance documents are formulated to assist students in smoothly progressing through their projects. As shown in Figure 3, the practical credit certification process entails project execution, credit recognition, and adherence to standardized formats for application forms and project reports. This enables students to prepare documentation in accordance with the required specifications. At the beginning of the project, special lectures on "how to conduct a project" are conducted to provide methodological guidance for students to advance their projects successfully.

During the project output phase, the focus extends beyond merely achieving tangible outcomes (e.g., project summary reports, prototypes, patents, papers, competition accolades, etc.). It also encompasses ensuring that students undergo the entire project process. Moreover, attention is directed toward the students' personal growth, encompassing the cultivation and enhancement of their innovation capabilities, research abilities, teamwork skills, and project management capabilities.

Establish a comprehensive and all-round support system for practical projects throughout the entire process

A comprehensive support system should be established to govern the entire lifecycle of student projects, from topic selection and implementation to final evaluation. This system must encompass all key stakeholders:

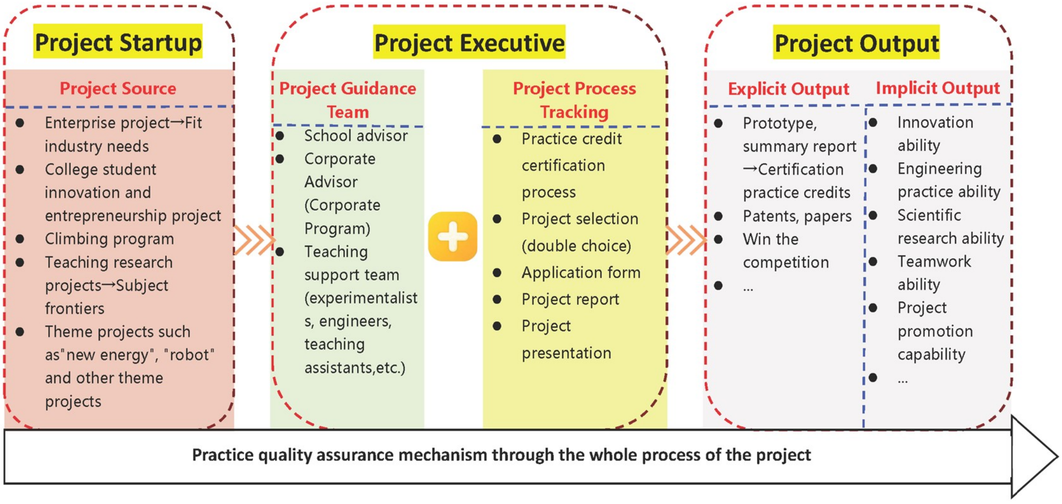

Figure 2. Practical quality assurance mechanism throughout the entire project process.

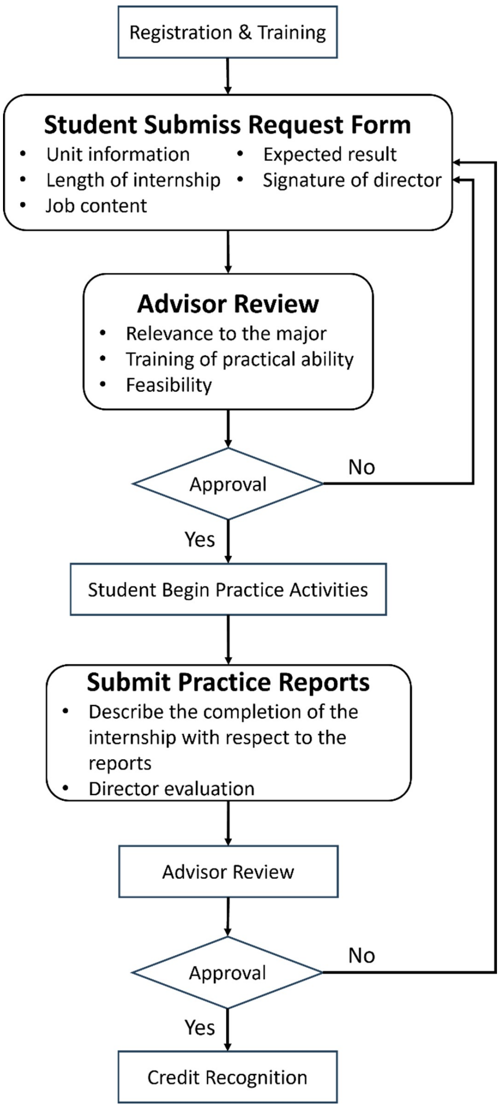

Figure 3. Process of recognizing practical credits.

students, faculty mentors, and administrative support teams. Central to this framework is a student-centric principle, where the support team's role is primarily administrative. Responsibilities include the collection and consolidation of project topics, coordination of student registration, management of progress reporting, and the archival of project materials to ensure the orderly and timely progression of all practical projects. Mentors (including company mentors and student mentors) are mainly responsible for project topic selection, guidance, and evaluation. With the assistance of mentors and support teams, students carry out projects according to established processes and requirements, ultimately achieving the expected outcomes. The all-encompassing support system for practical projects is illustrated in Figure 4.

Building a diverse and rich library of practical projects

Since its establishment, the Center has consistently provided students with a wide range of practical projects during the summer, emphasizing that ensuring the quality of practical projects is essential to the effectiveness of student practice. These practical projects include research projects from domestic and foreign university professor-led research groups (including projects from the Mechanical Engineering Department of SUSTech), allowing students to deeply engage in cutting-edge research projects. Additionally, some projects come from real-world engineering issues in companies, allowing students to experience the pulse and demands of the industry up close. The number of students who have participated in the Center's summer practical projects since 2017 is shown in Figure 5. Participating institutions include prestigious domestic and international universities such as Tsinghua University, Massachusetts Institute of Technology,

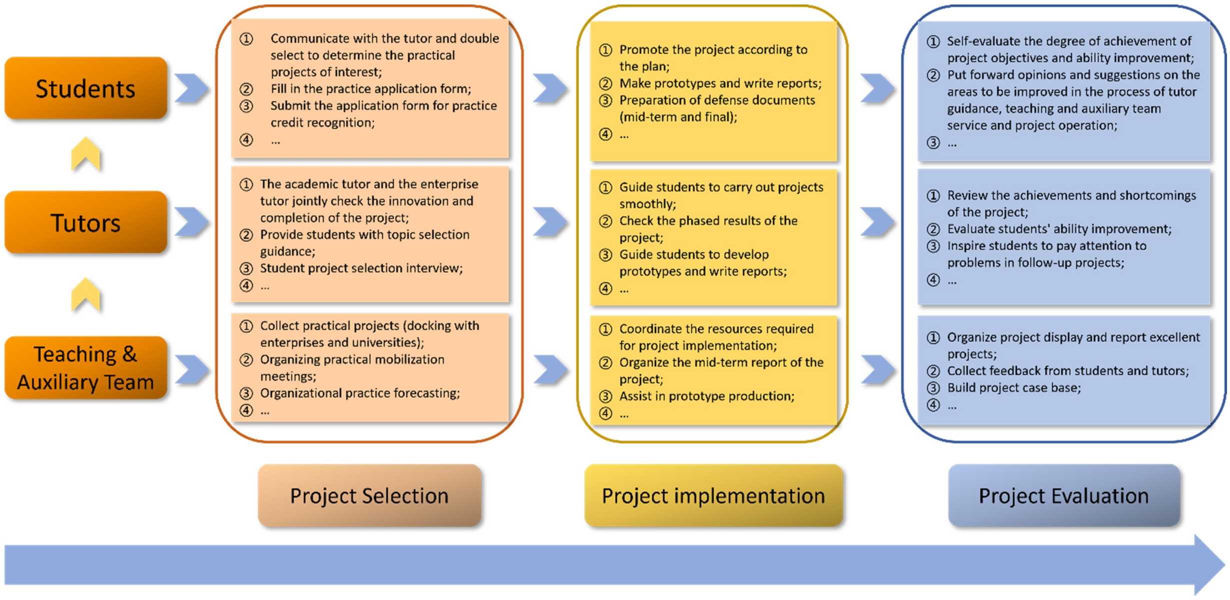

Figure 4. End-to-end, comprehensive practical project support system.

University of Notre Dame, Johns Hopkins University, Ohio State University, University of Southern California, University of Hong Kong, University of Michigan, Tohoku University (Japan), Kyushu University, Tsinghua-Berkeley School, and Huazhong University of Science and Technology. The participating high-tech companies included over 20 such as Shenzhen DJI Innovation Technology Co., Ltd. (DJI), Shenzhen Kino Dynamics Technology Co., Ltd., Narwal Intelligent Technology Co., Ltd., and Shenzhen Sunzon Technology Co., Ltd. These summer programs, with the involvement of top-tier universities from abroad, provided students with cross-cultural experiences, broadened their international horizons, and contributed to enhancing their global competence. Local high-tech companies also demonstrated high enthusiasm for participation, with some Chief Executive Officers (CEOs) expressing great anticipation for the fresh and innovative ideas that students may bring.

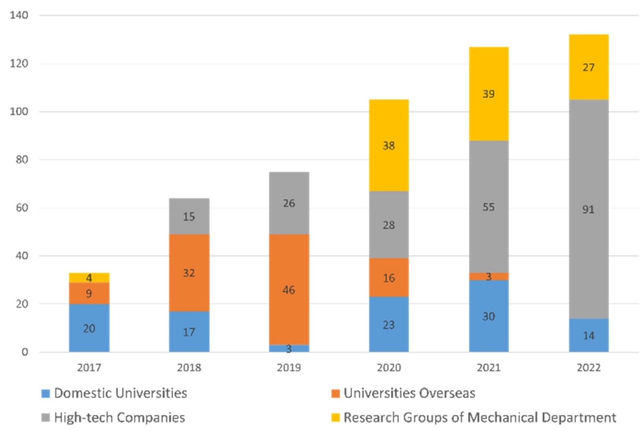

Figure 5. Number of students participating in summer practical projects.

Building a diverse student project showcase and communication platform

To promote communication and to showcase student project outcomes, the Center has continuously organized course exhibitions since 2018. Each exhibition has a specific theme. The first exhibition adopted the theme "Achieving Progressive Engineering Expression Based on Project-Driven Capabilities"; the second, "Exploring New Engineering Disciplines Based on Project-Driven Course Integration"; the third, "Building a Progressive Engineering Practice Platform"; and the fourth, "We Dream, We Design, We Build". The scale of the course exhibition has expanded from 51 projects in the first exhibition, which included two courses: "Manufacturing Engineering Cognitive Practice" and "CAD and Engineering Drawing", to more than 130 projects from 13 courses in the fourth exhibition. The course exhibition provides a platform for students from different grades and majors to learn from each other and communicate. Industry mentors are also invited to participate in project evaluations, fostering direct interaction and two-way communication between students and industry professionals.

The layout of the course exhibition projects is organized across three levels: cognitive practice, skill-oriented guided practice, and independent practice, allowing students to visually appreciate the progressive development of project capabilities. Projects are presented in various forms including physical prototypes, posters, and videos. Through the project exchanges on the same platform, students engage in deep cross-course, cross-discipline, and cross-grade communication and collaboration.

CONCLUSIONS AND SUGGESTIONS

Research conclusions

The Innovation Design and Advanced Manufacturing Center is based on the aim of cultivating innovative abilities among top undergraduate talents. It upholds the goals of supporting undergraduate teaching, serving undergraduate research, and establishing connections. The Center has established an innovative and comprehensive practice platform supported by three major platforms: Advanced Manufacturing Platform, Innovation Design Platform, and Automatic Control, Robotics, and AI Technology Platform.

The platform supports experimental teaching components of about 30 courses in innovation design, advanced manufacturing, energy, robotics, and other fields. It also accommodates independent practice components such as professional practice, innovation and entrepreneurship practice, comprehensive engineering training, graduation projects, discipline competitions, undergraduate research projects, and more.

The Center has developed a modular, hierarchical, and customizable practical course system and implemented a practice quality assurance mechanism that spans the entire project process. It has established a comprehensive support system for practice projects, detailed practice credit certification processes, a diverse practice project library, and a rich practice project communication platform.

The Center incorporates a multitude of authentic projects derived from real-world domestic and international industry scenarios. This initiative enables undergraduates to gain firsthand experience of the industry's technological landscape and ensures their engineering projects address current innovation needs and challenges. All projects are completed under the dual guidance of university professors and industry mentors. This model represents a key pathway for SUSTech, a new-model research university, to serve regional industrial development and to forge a novel ecosystem of industry-education integration.

The aforementioned aspects constitute the key advantages of this case study when compared to traditional engineering training centers at other research universities in China. Over several years of application, the Center has demonstrated success in supporting teaching, research, and industry engagement. The model has proven effective in fostering the interdisciplinary and comprehensive practical abilities of engineering students. Consequently, graduates from SUSTech have consistently achieved strong employment outcomes in recent years. A significant majority secure high-quality positions in emerging tech enterprises and Fortune 500 companies or pursue further studies at world-class universities, earning widespread acclaim from employers.

Limitations of the Study

This study is constrained by the absence of longitudinal data for a thorough evaluation of student learning outcomes. The Innovative Design and Advanced Manufacturing Center was founded in 2016, and a systematic mechanism for tracking student progress over the subsequent nine-year period was not in place. This resulted in insufficient quantitative data to robustly measure the long-term development of student competencies, thereby limiting the scope and generalizability of our findings.

A crucial direction for subsequent research involves collecting data across several key dimensions: (1) the development of higher-order thinking skills (e.g., problem-solving and creativity); (2) proficiency in practical and technical skills, evaluated via project execution efficiency; and (3) long-term career development indicators, such as graduate employment rates and employer satisfaction feedback. This approach is intended to generate valuable insights and a practical framework, offering a reference point for other higher education institutions.

Suggestions

Based on the findings of this case study, several policy recommendations are proposed:

Firstly, universities should improve the policy design for students' practical education. To cultivate students' practical abilities, universities should not only traditionally open doors to enterprises but also proactively engage with the industry, promoting close collaboration and synergistic engineering education among various innovation entities. By using structured, real-world industrial problems as a bridge, universities can enable students to truly feel the pulse of future industries and the challenges posed by key technologies, thereby fostering their interdisciplinary and comprehensive practical abilities.

Secondly, universities need to establish a robust and comprehensive quality assurance framework for their practical education systems, which encompass engineering training, hands-on teaching, summer projects, and other related programs. This framework should ensure that all practical education activities are designed, implemented, and evaluated to the highest standards, fostering an environment where students can develop their skills, knowledge, and competencies in a structured and supportive manner.

Thirdly, in practical teaching, we should actively promote high-level international industry-academia-research collaboration through meticulously designed courses and projects. By incorporating cutting-edge scientific and technological knowledge, as well as innovative ideas from the international forefront, we can continuously broaden the international perspectives of engineering students and enhance their global competence. In this manner, our graduates will possess the essential capabilities needed to thrive in the globalized era, encompassing multidimensional qualities such as an international knowledge base, cross-cultural communication skills, a global mindset, and an appreciation of international values.

DECLARATION

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Author contributions
Lu D developed the concept for the manuscript, reviewed the literature, formulated research questions, collected the data, conducted analyses and interpreted the data. Kang L contributed to the original draft preparation, review, and editing. Guo L organized resources, data curation and supervision. Ma YS developed original draft writing, reviewing and editing. Ke WD developed conceptualization, methodology, validation and project administration, and funding acquisition. All authors have read and approved the final version. All authors have read and approved the final version of the manuscript.

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Ethical approval
Not applicable.

Informed consent
Not applicable.

Conflict of interest
The author has no conflicts of interest to declare.

Use of large language models, AI and machine learning tools
None declared.

Data availability statement
No additional data.

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