Journal of Contemporary Educational Research, 2025, Volume 9, Issue 12
http://ojs.bbwpublisher.com/index.php/JCER
ISSN Online: 2208-8474
ISSN Print: 2208-8466

Towards Substantial Equivalence through Curricular Alignment in Sino-German Mechanical Engineering Education

Weiguang Su[1,2]*, Liying Gao[1,2]*, Li Wang[1,2], Wenhong Zhang[1,2], Shuhui Xu[1,2], Jin Du[1,2]

[1]School of Mechanical Engineering, Shandong Key Laboratory of CNC Machine Tool Functional Components, Qilu University of Technology (Shandong Academy of Sciences), Jinan 250353, China
[2]Shandong Institute of Mechanical Design and Research, Jinan 250031, China

Corresponding authors: Weiguang Su, weiguang.su@qlu.edu.cn; Liying Gao, gly@qlu.edu.cn

Abstract: Against the backdrop of globalization, the mutual recognition of engineering qualifications and the cross-border mobility of talent have emerged as pivotal issues in higher education reform. As global leaders in manufacturing, China and Germany share a profound strategic synergy in engineering talent cultivation. However, graduates from Chinese undergraduate mechanical engineering programs frequently encounter significant hurdles regarding "curricular alignment" when applying for Master's degrees at Germany's elite research universities (specifically the TU9 Alliance). These challenges often result in high rejection rates or severe academic maladjustment post-admission. Adopting a comparative higher education perspective, this study critically analyses the Master's admission mechanisms and undergraduate core curriculum systems of TU9 institutions, including RWTH Aachen, TUM, KIT, and the University of Stuttgart. Through a micro-level comparative analysis of syllabi, credit structures (ECTS conversion), and assessment paradigms in key modules—such as mathematics, engineering mechanics, and thermal-fluid sciences—this paper reveals structural discrepancies in "theoretical depth," "scientific orientation," and "process-oriented assessment" within Chinese engineering education. The findings indicate that the difficulty in achieving substantive equivalence stems fundamentally from the crowding out of professional hours by general education courses, the fragmentation of knowledge in core foundational modules, and a misalignment between Chinese credit calculations and European standards. Consequently, this paper proposes a reform scheme for mechanical engineering curricula aimed at international alignment. This includes modular curriculum reconstruction, learning-outcome-based syllabus design, and the establishment of a hybrid assessment system, providing theoretical support and practical pathways for Sino-German cooperative education and the internationalization of engineering education.

Keywords: Sino-German cooperative education; Mechanical engineering; Curriculum alignment; Modular curriculum system; ECTS; TU9

Online publication: December 31, 2025

1. Introduction and research background

The "Made in China 2025" strategy has become deeply integrated with Germany's "Industry 4.0," shifting cooperation in the high-end manufacturing sector from mere technology transfer to comprehensive joint talent cultivation. As one of the birthplaces of modern engineering education, Germany's higher engineering education system—particularly represented by the research universities of the TU9 Alliance—serves as a global benchmark due to its profound mathematical and physical foundations, rigorous scientific training, and close industrial linkages. According to the German Academic Exchange Service (DAAD), Chinese students have consistently been the primary source of international students in Germany, with the majority pursuing master's degrees in engineering [1].

However, German universities enforce extremely stringent audit processes for master's applicants. German research universities strictly adhere to the principle of "consecutivity" (*Konsekutivität*), which entails a deep assessment of whether the applicant's undergraduate curriculum matches the prerequisites of the target master's program in terms of content breadth, knowledge depth, credit load (measured in ECTS), and modular structure [2]. Although existing Sino-German cooperative curriculum systems often correspond in course titles, significant gaps remain in the substantive connotation of modular design and credit composition (e.g., autonomous learning loads, weighting of practical components) and the granular description of learning outcomes [3]. Consequently, applicants are frequently rejected or required to complete remedial undergraduate courses due to "insufficient curriculum alignment." Therefore, maintaining the characteristics of Chinese engineering education while achieving substantive equivalence with top international standards through curriculum reform has become a critical issue for Sino-German cooperative education and the construction of "New Engineering Disciplines" (*Xin Gongke*).

This study aims to transcend the limitations of previous research that focused on language training or macro-institutional comparisons by focusing on the "curricular DNA" at the micro-level [4]. By reverse-engineering the master's admission requirements of TU9 universities such as RWTH Aachen and KIT, this study precisely identifies the "shortcomings" and "blind spots" in the Chinese curriculum system [5]. The specific objectives of this research include: (1) Deconstructing German standards: Clarifying specific credit requirements and knowledge coverage standards in core fields like mathematics, mechanics, and thermodynamics at TU9 universities; (2) Diagnosing systemic deficiencies: Quantifying the "exchange rate loss" in ECTS conversion for Chinese engineering curricula and analyzing its causes; and (3) Proposing reform schemes: Designing an operational curriculum reconstruction guide for Sino-German cooperative programs and standard undergraduate majors aiming for international reform, thereby enhancing the international competitiveness of talent cultivation.

2. Analysis of the curriculum of undergraduate mechanical engineering in German universities

2.1. The "inverted pyramid" structure of the curriculum

The undergraduate mechanical engineering curriculum at German research universities (typically 6–7 semesters, 180–210 ECTS) exhibits a typical "inverted pyramid" structure. Foundational phase (Semesters 1–4): Highly homogenized, concentrating on the foundations of mathematics, natural sciences, and engineering sciences. This phase contains almost no electives, aiming to build a solid theoretical foundation.

Deepening phase (Semesters 5–6): Introduces specialized direction modules and the bachelor's thesis. German students face high-intensity professional screening from their first year, with high failure rates. This "broad entry, strict exit" mechanism ensures that survivors possess an extremely high level of academic literacy [6]. This structure stands in sharp contrast to the rhythm of Chinese universities, which typically follow a pattern of "general education in freshman year, foundations in sophomore year, and specialization in junior year."

2.2. Deep analysis of key core modules

Mathematics: Serving as the cornerstone of German engineering education, mathematics is emphasized for the systemic establishment of mathematical thinking, unlike the domestic tendency to view it merely as a computational tool. Mathematics courses are usually taught by the Mathematics Department specifically for engineering students and are of great difficulty. Notably, sections on Vector Field Theory and Partial Differential Equations (PDEs) are prerequisites for subsequent courses like Fluid Mechanics, Electromagnetics, and Finite Element Analysis [7]. Chinese students often face obstacles when applying for master's programs in control engineering due to a lack of credits in these areas.

Engineering Mechanics: Considered the core of the core by German universities, this typically includes: Statics, Elastostatics/Strength of Materials, Dynamics/Kinematics, and Fundamentals of Fluid Mechanics or Introduction to Continuum Mechanics. German undergraduates are generally required to master knowledge such as the Lagrange equations and Hamilton's principle, applying basic theories to solve engineering problems. in China, this content is usually found in Physics departments or the graduate-level course Advanced Dynamics. The Theoretical Mechanics taught to Chinese mechanical undergraduates often stops at the Newton-Euler system, with little involvement in energy methods.

Thermal-Fluid and Energy Sciences: This area emphasizes the abstraction of theory. Thermodynamics covers not only classical cycles but also deeply explores irreversible processes, entropy production analysis, equations of state for real gases, multi-component systems, and chemical equilibrium. Heat and Mass Transfer emphasizes the derivation of differential equations and numerical solution strategies rather than merely the application of empirical formulae. Chinese Engineering Thermodynamics often leans towards application (e.g., table look-ups, cycle calculations), with less focus on the axiomatic system of thermodynamics and microscopic explanations. Furthermore, domestic mechanical majors typically allocate fewer hours to fluid mechanics, failing to cover the complete derivation of the Navier-Stokes equations and the basics of numerical solutions.

Mechanical Design course module usually spans 2–3 semesters [8], which emphasizes systematic design methodology beyond mere components. Students must complete complex project assignments, such as gearbox or transmission system designs, including complete calculation dossiers, CAD modelling, and engineering drawings. The workload is often equivalent to an independent course. Whilst domestic curriculum design has similar components, there is a distinct gap in the requirements for standardization and innovation compared to German quality standards.

Practice: German engineering education places paramount importance on practice. Pre-internships, project designs, and graduation designs are closely integrated with actual enterprise operations and carry significant credit weight [9]. For instance, the Technical University of Berlin mandates internship components, and graduation designs usually stem from actual corporate problems. If the practical components of Chinese cooperative projects fail to align with the German side in terms of systematicity, authenticity, and assessment standards, the matching assessment will be negatively affected.

2.3. Coherence and depth of professional directions modules

German Master's programs usually feature specialized tracks (e.g., Intelligent Manufacturing, Automotive Engineering, Energy Technology), requiring applicants to have formed a coherent knowledge system in a specific direction during their undergraduate studies. This is manifested as a series of logically tight elective module combinations rather than scattered, superficial elective courses [10]. The Chinese curriculum system often suffers from "breadth without depth" in professional electives, making it difficult to form a "professional academic profile" recognized by the German side.

Many Chinese cooperative education programs suffer from structural issues such as "courses without modules," "ambiguous correspondence between credits and hours," "vague descriptions of learning outcomes," "lack of systematic integration in specialized courses," and "insufficient academic certification of practical links." These are the structural roots of the alignment gap [11–14].

3. Curriculum system restructuring design for enhanced alignment

3.1. Curriculum system restructuring: The "dual platform" model

3.1.1. Unified basic platform

Benchmarking against the generic core requirements of the German ASIIN accreditation for undergraduate mechanical engineering, a "Greatest Common Divisor" module group is established as compulsory for all students [15,16]. This platform ensures complete coverage of the German requirements regarding the breadth and depth of knowledge in mathematics, natural sciences, engineering mechanics, materials, design fundamentals, thermal-fluids, controls, and electrical engineering. Each module requires a bilingual (Chinese/English or Chinese/German) *Module Handbook*, clarifying its ECTS credits, total learning load composition, prerequisites, teaching content, specific learning outcomes, and assessment methods.

3.1.2. Specialized direction module platform

After the third year, highly structured "Directional Elective Module Packages" are established based on mainstream German Master's research directions (e.g., Intelligent Manufacturing Systems, Sustainable Energy Technology, Automotive Engineering, Microsystems Technology). Each package consists of 3–4 deeply related advanced courses, providing a total of 12–18 ECTS credits, ensuring students form a coherent "academic profile" recognized by the German side. Module content should reference the upper-level undergraduate or pre-Master's course settings of target TU9 institutions [17].

3.2. Pedagogical reform: From "knowledge inculcation" to "competence formation"

3.2.1. Introduction of "gateway exams" and "process load"

The reform attempts to introduce "separation of teaching and testing" and "high-difficulty final exams" in core foundational courses. The weight of "attendance" in regular grades is reduced, whilst the weight of "complex problem-solving assignments" is increased. Drawing on the German exercise class model (Übung), graduate teaching assistant positions are created to lead undergraduates in calculating complex problems, compensating for the limitations of large lecture classes [18].

3.2.2. Authentic engineering practice/internships

Moving away from "tourist-style" visits, the reform establishes deep school-enterprise cooperation bases, requiring students to undertake at least 12 weeks of full-time engineering internships in the 6th or 7th semester. The internship content must include technical work and require a detailed internship report signed by a corporate mentor [19]. This not only meets the internship requirements for German Master's admission but also enhances employment competitiveness.

3.2.3. Research-oriented undergraduate thesis

Topics for undergraduate graduation designs should be more academically exploratory rather than purely engineering drafting. Students are encouraged to write thesis abstracts or full texts in German or English and defend them according to academic norms, thereby enhancing the demonstration of research potential for research-oriented Master's applications.

3.3. Closed-loop optimization and assurance mechanisms

3.3.1. Dynamic benchmarking mechanism

An academic committee composed of professors from both China and Germany is established to continuously track the updates of module manuals in relevant majors at target German universities, building and maintaining a "German Master's Curriculum Requirement Database." The Chinese curriculum system is reviewed and adjusted periodically (e.g., every two years) based on this database.

3.3.2. Process feedback and personalized navigation

An "Academic Tutor System" is implemented, equipping students intending to study in Germany with dual tutors (Chinese and German/German-background). Tutors intervene early to guide students precisely according to target institution requirements, planning personalized course selection and academic activities, and utilizing summer schools or online courses to timely bridge identified credit or content gaps.

3.3.3. Quality accreditation and documentation standardization

Efforts are made to promote the exemption or recognition of Chinese cooperative programs or core curriculum modules by German partner institutions [20]. All course syllabi, module descriptions, and transcripts must provide standardized, bilingual official documentation, with formats and content specifications strictly benchmarking German requirements.

3.3.4. Data-driven assessment and continuous improvement

A graduate advancement tracking database is established to systematically collect detailed cases of students applying for German Master's degrees (including success and failure cases, German audit opinions, etc.). Data is analyzed regularly to form a closed loop of "Data Collection (Application Results) → Analysis and Diagnosis (Alignment Gaps) → Curriculum Optimization (System Adjustment)," achieving the iterative evolution of the curriculum system.

4. Conclusion and outlook

Enhancing curriculum alignment is the core solution to breaking the bottleneck of student advancement in Sino-German cooperative education and achieving the international substantive equivalence of talent cultivation. The reconstruction scheme proposed in this paper is not a simple replication of the German schedule but a deep-level re-engineering of the curriculum system based on the underlying logic and accreditation standards of German engineering education. By constructing a dual-layer structure of "Unified Basic Platform + Specialized Direction Modules," supplemented by four major guarantee mechanisms—dynamic benchmarking, process navigation, quality accreditation, and data feedback—the Chinese curriculum system can achieve precise docking with the German side in content, depth, structure, and certification, whilst maintaining its own characteristics.

Through the implementation of modular curriculum reconstruction, transparent ECTS conversion mechanisms, and deep pedagogical reforms, Chinese universities can not only significantly improve the success rate of graduates applying to top German universities but also fundamentally consolidate the mathematical and physical foundations of engineering talent. This cultivates excellent engineers who truly possess an international vision and the ability to solve complex engineering problems. This is not merely a tactical adjustment to serve student study abroad needs, but a strategic choice to promote the transition of Chinese higher engineering education from "large" to "strong."

Future research and practice could further explore: utilizing digital tools to develop intelligent diagnosis and early warning systems for curriculum alignment; extending this model—based on accreditation standards and modular docking—to other engineering fields such as Electrical Engineering and Computer Science; and deeply researching how to further integrate teaching resources and process evaluation through virtual teaching and research rooms and remote joint graduation designs under the "4+0" model. This will continuously promote the connotative and high-quality development of the internationalization of China's higher engineering education.

Funding

The Sino-German Cooperative Education Project of Qilu University of Technology (Shandong Academy of Sciences) and the Teaching Research Project of the Shandong Provincial Department of Education (SDYAL2024093)

Disclosure statement

The authors declare no conflict of interest.

References

[1] Auschner E, Jiang L, 2025, Implementing Chinese Student Support Services at a German Technical University. Journal of International Students, 15(5): 63–80.

[2] Investigation Report on German Engineering Education Accreditation, Reform and Development, 2006, Research in Higher Education of Engineering, (1): 4.

[3] Fu X, Gao Y, Jiang L, 2024, Exploration of the Talent Cultivation System in Sino-German Cooperative Education under the Background of International Engineering Education Accreditation. Western China Quality Education, 10(16): 91–94.

[4] Keprate A, Woodford S, Borrajol R, 2023, From Theory to Practice: Leveraging Project-Based Learning to Cultivate Student Engagement in Mechanical Engineering Education, 2023 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM).

[5] Jie K, 2023, Discussion on Practice Teaching Model of Mechanical and Electronic Engineering Specialty in the View of New Subject. The Theory and Practice of Innovation and Entrepreneurship, 6(09): 133–135 + 43.

[6] München TU, 2024, Examination and Study Regulations for the Bachelor's Degree Program in Mechanical Engineering at the Technical University of Munich.

[7] Module Handbook Bachelor's Program Mechanical Engineering International (B.Sc.), 2025.

[8] Ruiz-Torrubiano R, Knopp S, Krystallidis A, et al., 2024, A Scheduling Perspective on Modular Educational

Systems in Europe. Heliyon, 10(21): e39694.

[9] Jinye Z, 2020, Comparative Study on the Practice Teaching System of Engineering Colleges between China and Germany, dissertation, Harbin University of Science and Technology.

[10] Dexin H, 2022, Construction Logic and Action Path of Engineering Education Accreditation System in Germany. Higher Education Development and Evaluation, 38(1).

[11] Kun G, 2023, Research on the Implementation Path and Optimization Strategy of Industry-Education Integration in Application-Oriented Universities—Take the Mechanical Major of Shanxi D University as an Example.

[12] Ye Y, 2022, Study on the Problems and Strategies of Talent Training of Mechanical Majors under the Background of Emerging Engineering, dissertation.

[13] Yijing Z, 2021, A Comparative Study on the Reform of Undergraduate Engineering Education between China and the United States for Advanced Manufacturing, dissertation, Harbin University of Science and Technology.

[14] Gan M, 2021, A Comparative Analysis of Practical Teaching for Undergraduate Mechanical Engineering Majors in China and the United States. Journal of Higher Education, 7(32): 38–41.

[15] Qi Z, 2021, Research on the Optimization Strategy of the Talent Training Mode of Local Colleges and Universities under the Background of Engineering Accreditation-Based on the Analysis of the Mechanical Specialty of Shandong D College, dissertation.

[16] Jianghua H, 2020, Major Reform and Practice Oriented by Engineering Education Accreditation, dissertation.

[17] Wei C, Hongxi W, Yunbo S, et al., 2021, From "Differential Learning" to "Broadening International Perspectives": A Comparative Study of Teaching Models for Cultivating Mechanical Engineering Talents in Chinese and Foreign Universities. Journal of Higher Education, (3): 21–24, 9.

[18] Van Den Beemt A, Macleod M, Van Der Veen J, et al., 2020, Interdisciplinary Engineering Education: A Review of Vision, Teaching, and Support. Journal of Engineering Education, 109(3): 508–555.

[19] Jinjin L, Peiqing Y, 2020, Exploration on the Integrated Project-based Research-oriented Comprehensive Practical Teaching Mode under the Background of Emerging Engineering Education. China University Teaching, (10): 58–61.

[20] Hongtao X, Wei L, 2019, Research on the Improvement of Curriculum System and Course Content under the International Talent Cultivation Mode. Research in Higher Education of Engineering, (S1): 90–93.