Reform and Exploration on Physical Chemistry Curriculum in Local Colleges and Universities under the Background of Emerging Engineering Education

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Abstract: *Under the framework of Emerging Engineering Education, traditional disciplines such as energy, chemical engineering, and materials science are being urged to transform and modernize. This work takes the Energy Chemical Engineering major at Guilin University of Technology in China as a case study. By focusing on demand-oriented goals and program-specific characteristics, it addresses key issues in the Physical Chemistry curriculum through systematic reconstruction of the knowledge framework, development of multi-dimensional teaching resources, adoption of diverse teaching approaches, and implementation of a three-dimensional assessment system under the paradigm of smart teaching. The ultimate objective is to cultivate high-quality emerging engineering professionals with strong practical ability, innovative capacity, and global competitiveness.*

Keywords: *physical chemistry; curriculum reform; emerging engineering education; local colleges*

1. Introduction

In response to the technological revolutions and industrial transformations, China's Ministry of Education launched the Emerging Engineering Education initiative in 2017 to support national strategies like "Made in China 2025" [1]. Since then, a series of strategic frameworks — namely the "Fudan Consensus", the "Tianjin Action", and the "Beijing Guide"—have been successively introduced to foster high-caliber and interdisciplinary engineering professionals with enhanced practical skills, innovative capacity, and international competitiveness [2,3].

Emerging Engineering Education serves as a strategic initiative for reshaping higher education in China, emphasizing integration with cutting-edge fields such as new energy, new materials, and artificial intelligence. This paradigm not only promotes the development of emerging disciplines but also drives the transformation, upgrading, and innovation of traditional programs, including energy, chemical engineering, materials science, environmental engineering, bioengineering, and pharmaceutical sciences [4,5]. Within this context, Physical Chemistry stands out as a fundamental and compulsory course across a wide range of science and engineering majors [6,7]. It aims to equip students with essential knowledge and skills in thermodynamics, chemical kinetics, and electrochemistry, enabling them to analyze, calculate, and apply these principles to real-world scenarios in daily life, industrial production, and scientific research. As such, Physical Chemistry plays a pivotal role in bridging theoretical foundations with practical applications and serves as a crucial link in cultivating engineering professionals with strong analytical thinking and interdisciplinary problem-solving capabilities.

2. Current Issues and Challenges for the Physical Chemistry Curriculum

Currently, the development of Emerging Engineering Education remains in its early stages at many local universities and colleges, including Guilin University of Technology. Consequently, the Physical Chemistry curriculum faces several interrelated and systemic challenges.

The "Three Difficulties and Three Deficiencies": The course is commonly perceived as difficult due to three main aspects: abstract theoretical content, complex conceptual frameworks, and intensive mathematical derivations and calculations. This has led to a general sense of intimidation and disengagement among students. Consequently, graduates often exhibit three deficiencies: a lack of distinctive disciplinary features linked to the university and the program, insufficient practical engineering skills, and underdeveloped technological innovation capacity.

Monotonous teaching resources and methods: Under the traditional teacher-centered and offline-only teaching paradigm, the course relies heavily on low-dimensional, linear instructional resources, outdated teaching platforms, and rigid delivery methods. This approach limits opportunities for meaningful student engagement, fails to foster intrinsic learning motivation, and diverges from modern student-centered educational philosophies. As a result, students demonstrate limited initiative, weak independent learning skills, and an inadequate ability to integrate and apply knowledge creatively in real-world contexts.

Oversimplified assessment process: The current assessment system is overly focused on theoretical examination, often confined to written tests that emphasize memorization and standard problem-solving. There is a lack of multi-dimensional evaluation tools that assess students' practical ability, innovative thinking, and real-time application of knowledge. Moreover, the feedback mechanism is weak, with limited interaction between instructors and students, which hinders timely academic support and fails to encourage formative improvement. This one-sided evaluation structure contributes to the insufficient development of students' comprehensive competencies.

3. Curriculum Reform of Physical Chemistry

To address the core challenges faced by traditional engineering-oriented Physical Chemistry courses—namely the "Three Difficulties and Three Deficiencies", monotonous teaching resources and methods, and oversimplified assessment process—we identified three key instructional pain points: insufficient disciplinary identity and weak practical skills, low student motivation and innovation, and limited effectiveness in professional cultivation.

To overcome these limitations, the course implements three integrated measures as shown in Figure 1: curriculum reconstruction and a "three-pronged" practical framework to enhance disciplinary specialization and practical skills; the development of a "5-Resource, 4-Method, 3-Stage, 2-Spatial, 1-Centred" teaching model to enrich learning resources, modernize pedagogy, and to support active learning and innovation capacity; and the establishment of a "comprehensive, multi-dimensional, layered" formative assessment system to cultivate well-rounded engineering graduates with strong academic foundations and practical competence. Together, these initiatives aim to cultivate high-quality, application-oriented engineering talents with enhanced practical ability, creativity, and international competitiveness.

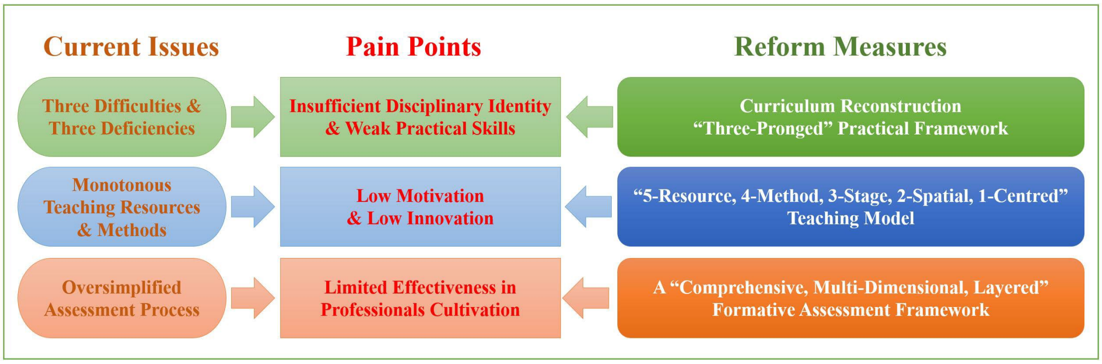

Figure 1. Schematic diagram of curriculum reform of physical chemistry.

3.1 Curriculum Reconstruction and a "Three-Pronged" Practical Framework

To address the "Three Difficulties and Three Deficiencies", the course content was restructured around demand-driven principles and disciplinary specialization, while a "three-pronged" practical framework was introduced to enhance application-oriented capabilities (Figure 2).

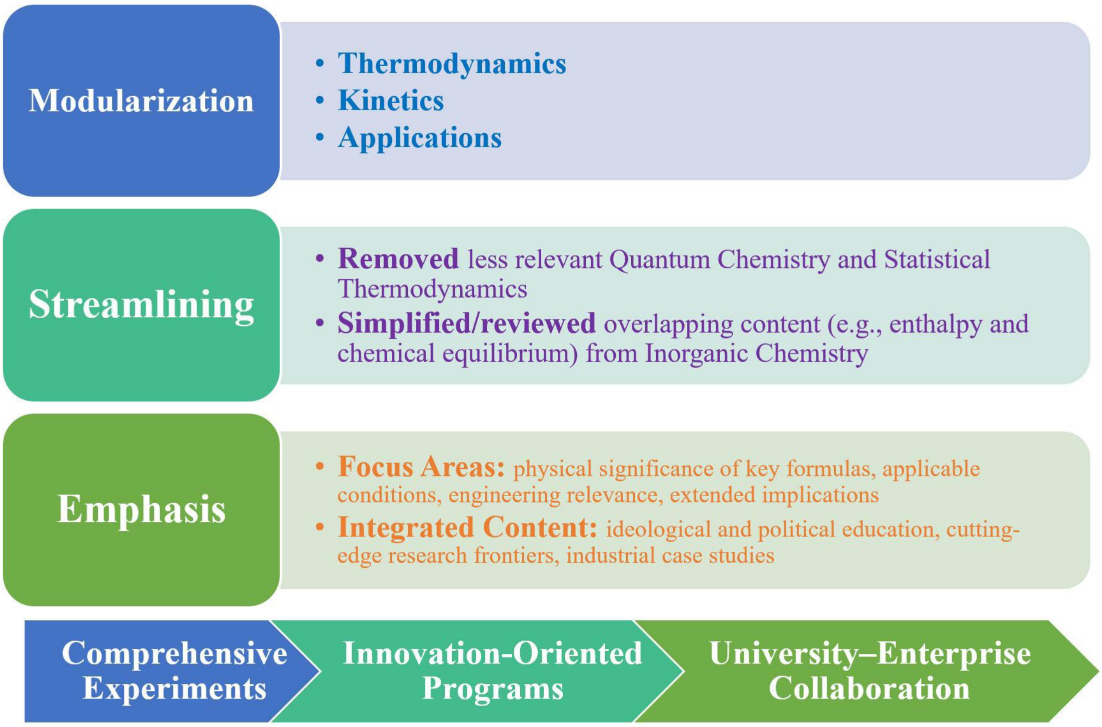

Figure 2. The curriculum reconstruction and a "three-pronged" practical framework.

In terms of curriculum restructuring, in response to issues such as limited teaching hours, extensive and abstract content, and a disconnect between theory and practice, the course was reorganized into three major thematic modules: Thermodynamics, Kinetics, and Applications. Obscure theoretical topics less relevant to the discipline, such as Quantum Chemistry and Statistical Thermodynamics, were removed to streamline the content and build a more structured, progressive knowledge system with clearer conceptual connections. To align with the "practice-oriented" objectives of engineering education, overlapping topics with other foundational courses (e.g., enthalpy and chemical equilibrium from Inorganic Chemistry) were simplified or briefly reviewed. More emphasis was placed on explaining the physical significance, applicable conditions, practical relevance, and extended implications of key formulas, enhancing both depth and applicability. Furthermore, the restructured curriculum integrates ideological and political education, cutting-edge disciplinary developments, and real-world industrial case studies, helping students bridge theoretical knowledge with societal needs and engineering challenges.

A "three-pronged" practical framework is implemented in response to the growing demand for skilled professionals in the energy and chemical industries, particularly in the field of new energy electrochemistry: comprehensive laboratory experiments, innovation-driven competitions, and university–industry collaboration. First, a series of hands-on comprehensive experiments were developed, including modules on electrochemical battery assembly, performance evaluation, and optimization techniques. Students are also encouraged to participate in faculty-led research projects in laboratory settings, where they can cultivate the ability to solve complex problems in energy-related engineering contexts. Second, innovation-oriented programs were embedded into the teaching process to stimulate creativity and interdisciplinary thinking. Students are actively guided to participate in competitions such as the "Green Energy Technology Application Challenge" and national-level "College Student Innovation and Entrepreneurship Training Programs." These competitions serve as platforms for learning through challenge, promoting the integration of theoretical learning with practical innovation and entrepreneurial mindset development. Third, university–enterprise collaboration was significantly strengthened. Measures include the establishment of on-campus training bases, structured off-campus internships, alumni visits, industry expert lectures, and faculty placements in enterprises. These efforts aim to expose students to real-world industrial environments, foster deeper understanding of modern production systems, and ultimately enhance their engineering practice and innovative problem-solving capabilities.

3.2 Development of a "5-Resource, 4-Method, 3-Stage, 2-Spatial, 1-Centred" Teaching Model

To overcome the limitations of traditional teaching resources and methods, a composite teaching model was developed by integrating five types of resources as shown in Figure 3: national-level flipped MOOCs, self-developed micro-lecture content, online animations and diagrams, thematic case banks, and intelligent question databases. This is complemented by four teaching approaches: blended online-offline delivery, visualization-based instruction, case-based learning, and practice-oriented teaching. Learning is structured around a three-stage cycle (pre-class, in-class, post-class), leveraging both physical and virtual teaching environments, with the student at the center.

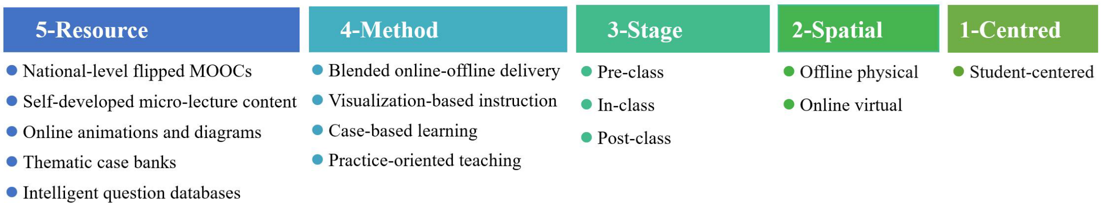

Figure 3. "5-Resource, 4-Method, 3-Stage, 2-Spatial, 1-Centred" Teaching Model.

The five resources collectively form a comprehensive teaching system: national-level MOOCs content expands disciplinary horizons; online courseware and micro-videos reinforce conceptual frameworks; dynamic visual tools demystify abstract theories; real-world cases incorporating scientific, industrial, and ideological elements foster applied thinking; and real-time question banks aid in consolidating knowledge.

Building upon these resources, the following four pedagogical approaches were implemented: blended learning via platforms such as Rain Classroom and Zhihuishu enables continuous learning monitoring, personalized support, and process tracking; visualization pedagogy transforms complex formulas into interactive diagrams, videos, and 3D models; case-based instruction integrates industry scenarios and ideological content to promote application; practice-based learning includes virtual simulations, experimental research, and academic competitions to enhance engineering creativity.

Within this enriched learning ecosystem, a three-stage closed-loop model is implemented to promote active and autonomous learning. In the pre-class stage, online platforms distribute preparatory materials, and students complete pre-tests and mind maps to develop autonomous learning habits. During in-class sessions, instruction incorporates digital resources and case studies, employing inquiry-based discussions, real-time quizzes, brainstorming, and group collaboration, all supported by real-time learning analytics. In the post-class phase, students engage in either individual tasks—such as exercises—or collaborative projects, including presentations, posters, and videos, with learning reinforced through peer review and online assessments.

By integrating premium online courses from top universities and instructors with immersive virtual simulation platforms, as well as offline resources such as comprehensive laboratory experiments, renewable energy competitions, and university–industry collaborative platforms, the model achieves synergy between dual learning spaces—virtual and physical—thus enhancing students' capacity for knowledge application and engineering innovation. This "two-spatial" coordination ultimately supports the realization of a student-centered educational philosophy.

3.3 A "Comprehensive, Multi-Dimensional, Layered" Formative Assessment Framework

In response to the need for more nuanced and process-oriented evaluation in the context of Emerging Engineering Education, the course implements a formative assessment framework defined by its comprehensiveness, multi-dimensionality, and layered structure. Moving beyond traditional outcome-based evaluations, this approach systematically assesses students' engagement, collaboration, and innovation throughout the learning process, aiming to cultivate well-rounded engineering graduates with strong academic foundations and practical competence. The overall course grade is determined equally by formative assessment (50%) based on the framework below and a summative final examination (50%) as shown in Figure 4.

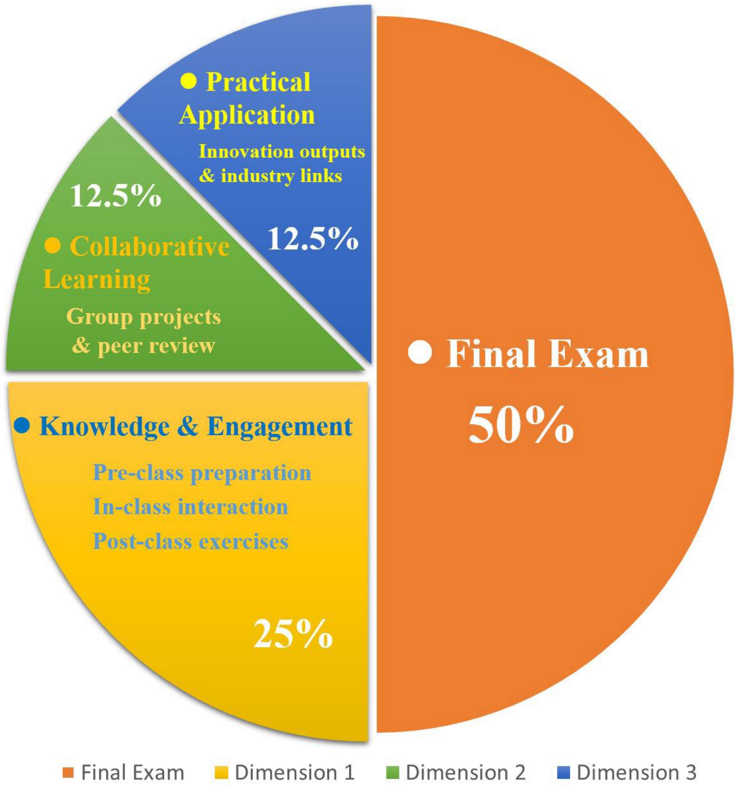

Figure 4. The "Comprehensive, Multi-Dimensional, Layered" Formative Assessment Framework.

The first dimension emphasizes knowledge acquisition and expressive engagement (25%). Pre-class learning tasks—such as watching lecture videos, completing preparatory quizzes, and creating mind maps—are tracked through platforms like Rain Classroom and Zhihuishu. In-class sessions involve interactive elements, including QR check-ins, real-time quizzes, short presentations, and bullet-screen interaction, enabling students to express understanding in diverse formats. Post-class exercises further consolidate knowledge. This dimension not only ensures content mastery but also nurtures students' confidence, communication skills, and intrinsic motivation.

The second dimension focuses on collaborative learning and peer interaction (12.5%). During the course, students are encouraged to explore abstract theories or applied topics in small groups, with clearly defined tasks that foster inquiry, role differentiation, and cooperative problem-solving. Peer review is used to stimulate mutual learning and reflective thinking, while instructors provide structured feedback and thematic summaries to deepen understanding. This collaborative approach breaks away from passive learning, helping students develop communication skills, adaptability, and a shared sense of responsibility—all of which are essential for success in interdisciplinary engineering contexts.

The third dimension targets practical application and creative thinking (12.5%). Students are required to extend their learning beyond the classroom through independent research, industrial visits, experimental practice, or participation in innovation competitions. Outputs such as posters, videos, and presentations integrate theoretical understanding with real-world relevance. This dimension supports the development of interdisciplinary problem-solving, engineering practice, ethical awareness, and environmental consciousness.

Together, these three formative assessment dimensions (totaling 50% of the final grade) provide a dynamic and holistic understanding of student progress throughout the course. Combined with the summative final exam (50%), this framework helps cultivate the core qualities required of next-generation engineering professionals.

Conclusion

In summary, in response to the demands of Emerging Engineering Education, the proposed teaching reform aims to enhance the Physical Chemistry curriculum through a student-centered approach grounded in local characteristics and disciplinary foundations. By addressing key challenges—including the “Three Difficulties and Three Deficiencies”, limited teaching resources and methods, and oversimplified assessment—a holistic strategy was implemented involving curriculum restructuring, diversified resources, smart teaching, and three-dimensional evaluation. This approach aims to cultivate high-quality emerging engineering professionals with strong practical ability, innovative capability, and global competitiveness.

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