

Engineering Problem-Driven Pedagogy and Three-Dimensional Mapping: Exploring Reform Pathways for Organic Chemistry in the Context of Emerging Engineering Education

Bin Guo*, Jing Zhang, Qirui Guo, Zhongxue Fang, Zongtang Liu

School of Chemical and Environmental Engineering, Yancheng Teachers University

No. 2 Xiwang Street, Yancheng 224007, China

*E-mail: guob@yctu.edu.cn

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Abstract

The development of Emerging Engineering Education (EEE) imposes elevated requirements on the talent cultivation in applied chemistry, emphasizing the synergistic development of engineering thinking, interdisciplinary integration, and innovative ability. As a core course, Organic Chemistry currently confronts multiple challenges, including a disconnect between course content and industrial needs, an overemphasis on knowledge transmission at the expense of innovative ability cultivation, superficial ideological and political education, and a monolithic evaluation system. In line with the requirements of the "Excellence Engineer Education and Training Program 2.0" initiative, this paper systematically analyzes the specific manifestations and underlying causes of these challenges. It further puts forward targeted reform strategies: reforming teaching content by adopting an "engineering problem-driven" approach, optimizing teaching resources by means of case library development and virtual simulation technology, adopting a "seamless integration" method for the integration of ideological and political education into the curriculum, and establishing a diversified and quantitative evaluation system. Teaching practice demonstrates that this integrated reform covering content, methodology, and evaluation can effectively enhance teaching quality, cultivate students' engineering literacy and innovation capabilities, thereby providing a practical reference for adapting the applied chemistry curriculum to meet the requirements of Emerging Engineering Education.

Keywords: Organic Chemistry, Emerging Engineering Education, Challenge, Reform

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1. Introduction

The development of Emerging Engineering Education (EEE), guided by the action framework comprising the "Fudan Consensus", "Tianjin University Initiative", and "Beijing Guidelines", aims to transform engineering education from a discipline-centric model to an industry-demand-driven paradigm—with a distinct emphasis on interdisciplinary integration and the cultivation of innovative capabilities.^[1-3] The "Fudan Consensus" advocates the establishment of an interdisciplinary engineering education system, emphasizes deepening the integration between disciplinary knowledge systems and real industrial demands, and focuses on nurturing innovative "stem cell-type" talents. The "Tianjin University Initiative" takes real-world engineering projects as a core driver, restructures the curriculum through the "Six Questions" pedagogical approach, and seeks to achieve synergy between the development of practical skills and the cultivation of professional values. The "Beijing Guidelines", positioned at the national strategic level, push for the development of standardized, modular, and systematic curriculum systems, so as to facilitate the organic linkage between the education chain, talent chain, and industry chain. Collectively, these three initiatives jointly constitute an integrated "concept-standard-practice" pathway for EEE, thereby providing a comprehensive theoretical and practical framework for the high-quality cultivation of engineering talents.^[4]

Organic Chemistry serves as a fundamental discipline for applied chemistry, pharmaceutical engineering, materials science, and numerous other related fields, exerting a pivotal role in key areas such as functional

molecule design, pharmaceutical synthesis, energy materials development, and other associated domains. Nevertheless, the current Organic Chemistry teaching paradigm is confronted with multiple challenges: the curriculum lags behind the latest technological advancements, the teaching methodology is overly dependent on one-way knowledge transmission, the assessment approaches remain monotonous, and the integration of ideological and political education stays superficial. These issues collectively impede the course's capacity to meet the talent cultivation demands of Emerging Engineering Education (EEE)—especially the demand for interdisciplinary and innovative talents.^[5-8] For the applied chemistry discipline in particular, shifting Organic Chemistry teaching from a knowledge-dissemination focus to a competency-development orientation has emerged as an urgent imperative. In response to this need, this study, in line with the requirements of the "Excellence Engineer Education and Training Program 2.0" initiative, carries out targeted reforms in Organic Chemistry teaching. These reforms encompass curriculum content restructuring, pedagogical innovation, in-depth integration of ideological and political education, and optimization of the evaluation system. The core objective is to enhance students' engineering practical capabilities and innovative literacy, thereby providing valuable insights for adapting the talent cultivation system of the applied chemistry discipline to the development needs of EEE.

2. Teaching Dilemmas in the Organic Chemistry Curriculum for Applied Chemistry Majors

2.1 Disconnect Between the Curriculum System and the Needs of Emerging Engineering Talent

The current Organic Chemistry curriculum system remains largely rooted in a traditional disciplinary structure, overemphasizing the systematicness and comprehensiveness of knowledge within a single disciplinary framework. This orientation results in a notable disconnect from the developmental demands of emerging industries and technologies. These issues manifest in three key respects: First, the course content continues to focus primarily on classical organic reaction mechanisms and synthesis methods, failing to effectively integrate with cutting-edge fields such as green chemistry and sustainable chemical processes. Second, the curriculum inadequately reflects interdisciplinary characteristics, with tenuous links to related domains including materials science, bioengineering, and environmental engineering. Third, the laboratory component remains centered on verification-based experiments, lacking integrated and design-oriented projects—an oversight that impedes the cultivation of students' ability to solve complex engineering problems.

2.2 Imbalance Between Knowledge Transmission and Innovation Capability Cultivation

The prevailing teaching model shows a distinct inclination to prioritize knowledge transmission over competency development. In terms of teaching methods, instructors often adopt a "cramming" approach, overemphasizing the memorization and rote reproduction of reaction mechanisms while overlooking the cultivation of scientific thinking methods. This instructional style leads to students who can proficiently memorize numerous chemical reactions yet lack opportunities to translate theoretical knowledge into practical problem-solving skills. Concurrently, the course design lacks adequate inquiry-driven elements, providing students with limited opportunities to engage in full-cycle research training processes. This gap directly hinders the development of innovative thinking and independent problem-solving capabilities. A direct consequence of this training model is that students often struggle to apply acquired knowledge to real-world engineering challenges, resulting in the so-called "high scores but low ability" phenomenon.

2.3 Superficial Integration of Ideological and Political Education

Current efforts to integrate ideological and political education into the curriculum are plagued by formalism and superficiality. The incorporation of ideological and political elements tends to be mechanistic, relying on a simplistic "labeling" method—for example, mechanically inserting a scientist's biography when explaining a chemical reaction, rather than organically integrating the cultivation of values (e.g., scientific spirit, engineering ethics) into the transmission of professional knowledge. Furthermore, this integration lacks a systematic design framework, failing to establish a comprehensive value-guidance system. This "two-tiered separation" (i.e., decoupling of professional knowledge and value cultivation) not only impairs the effectiveness of ideological and political education but also dilutes the educational role of professional training.

2.4 One-Dimensional Teaching Evaluation

The existing course evaluation system has notable deficiencies, primarily evident in three aspects: First, evaluation methods are excessively simplistic, relying heavily on closed-book final examinations. The exam content places disproportionate emphasis on the memorization and recall of foundational knowledge, while lacking effective assessment of students' engineering practical abilities and innovative thinking. Second,

evaluation criteria are insufficiently scientific: exam scores typically account for an excessively large proportion of the final grade (often up to 70%), whereas process-oriented and formative assessments are assigned insufficient weight—failing to fully reflect students' learning outcomes and capability development. Third, evaluation content is one-sided: it primarily tests students' mastery of theoretical knowledge, seldom incorporating evaluations of comprehensive competencies such as engineering thinking, innovative design, and teamwork. This one-dimensional evaluation system not only fails to accurately and effectively assess student learning but may also exert a negative influence on students' learning strategies, fostering a test-centric learning orientation.

3. Reform Pathways and Practical Exploration for the Organic Chemistry Curriculum in Applied Chemistry

3.1 Restructuring of Course Content

Course content restructuring should be centered on engineering practice, establishing a three-level knowledge system of "Foundation-Application-Innovation". Specific reform measures can be implemented in the following three aspects: First, knowledge modules should be reconstructed around practical engineering cases. For instance, take "Optimization of the synthesis process for the antiviral drug Lopinavir" as a project carrier, integrating knowledge points such as retrosynthetic analysis, chiral induction, and catalyst selection into authentic engineering scenarios. Second, an interdisciplinary knowledge graph should be developed to integrate organic chemistry knowledge with relevant content from fields including computational chemistry, process engineering, and materials science. For example, when explaining pericyclic reactions, incorporate content related to quantitative molecular orbital theory calculations to help students build a systematic understanding spanning from molecular design to property prediction. Third, construct a three-tier teaching content system of "Concept-Method-Application", ensuring the effective transmission of foundational knowledge while strengthening the cultivation of engineering thinking methods and innovative capabilities.

3.2 Innovative Configuration of Teaching Elements

The innovative configuration of teaching elements should emphasize the integration of theory and practice, with specific measures including the establishment of a tripartite teaching resource system consisting of a "Case Library-Virtual Platform-Experimental Platform". First, collect and organize prominent recent scientific research breakthroughs and engineering cases (e.g., the latest advances in photocatalysis and electrocatalysis for organic synthesis) and transform them into standardized teaching cases. Second, introduce virtual simulation technology to develop interactive teaching platforms—such as the organic synthesis optimization in microreactors virtual experimental system—allowing students to independently design experimental protocols and observe reaction outcomes under different parameter settings. Third, implement Project-Based Learning (PBL), enabling students to collaborate in groups to complete full project cycles (from molecular design to synthesis route optimization), thereby fostering their engineering practical abilities and team collaboration skills.

3.3 Disciplinary Integration of Ideological and Political Education

The integration of ideological and political education into the curriculum should adhere to the principle of "seamless integration like salt dissolving in water", achieving an organic fusion of professional knowledge and value guidance. Specific implementation pathways are as follows: First, excavate the inherent ideological and political elements in professional knowledge and develop a "Knowledge Point-Value" mapping table. For instance, when teaching the nitration reaction of aromatic compounds, highlight the potential hazards of the reaction conditions and the proper handling of waste materials to foster students' risk assessment capabilities and raise their awareness of safety and environmental protection. Second, design scenario-based teaching cases (e.g., the project "Design and evaluation of sustainable organic materials"), guiding students to comprehensively consider multiple factors—including performance, cost, and environmental impact—during the material design process, thereby fostering their awareness of engineering ethics and social responsibility. Third, organize interdisciplinary ethics seminars, such as student debates on topics like "the ethical boundaries of artificial intelligence (AI) in drug design", to enhance students' critical thinking and value judgment capabilities.

3.4 Diversification and Quantification of Evaluation Standards

Establishing a scientific and rational diversified evaluation system should start with the following measures: First, refine the evaluation content system by building a three-dimensional "Knowledge-Ability-Competency" evaluation framework—assessing students' mastery of foundational knowledge while enhancing the evaluation of their engineering practical abilities, innovative thinking, and professional literacy. Second, optimize the

combination of evaluation methods: reduce the weight of the final examination to less than 50% of the total grade, and increase the proportion of process-oriented assessments (e.g., project reports, experimental design schemes, and seminar participation). Third, innovate evaluation tools by introducing AI-enabled assessment instruments: for example, use interactive AI to analyze the quality of students' reports, and utilize virtual simulation platforms to record students' process performance and provide intelligent evaluation. Finally, establish a continuous improvement mechanism, regularly collecting feedback from students and employers to continuously refine the evaluation standards and methods.

4. Conclusion

The reform of the Organic Chemistry curriculum for Emerging Engineering Education (EEE) is a systematic project. To address core challenges—including the disconnect between the curriculum and industrial needs, inadequate cultivation of innovative capabilities, superficial integration of ideological and political education, and a unitary evaluation system—this paper proposes a comprehensive reform pathway. This pathway encompasses restructuring teaching content based on an engineering problem-driven model, innovating teaching resource configuration through the integration of virtual and physical platforms, deepening the integration of ideological and political education via seamless infusion, and optimizing evaluation standards through diversification and quantification. Teaching practice has shown that this integrated reform system effectively arouses students' learning interest, facilitates the conversion of theoretical knowledge into practical competencies and comprehensive literacy, and realizes the integration of value guidance and professional education. Nevertheless, future reforms still face challenges, such as the need for sustained development of high-quality teaching resources and the imperative to strengthen teachers' comprehensive capabilities. Going forward, deepening industry-academia collaboration, continuously refining intelligent teaching and evaluation systems, and ultimately constructing a sustainable, dynamically evolving curriculum ecosystem for applied chemistry will be essential. These efforts are critical to providing strong support for cultivating outstanding engineering talents who meet the demands of EEE.

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