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Design and Research of an AI-Empowered Blended Teaching Model for Organic Chemistry in Environmental Engineering

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Abstract: Organic Chemistry is an important foundational course for Environmental Engineering students. However, conventional teaching often faces challenges such as the abstract content, insufficient disciplinary relevance, and low student engagement. To address these issues, this study proposes an online–offline blended teaching model integrating AI empowerment with environmental case-based learning, according to the training objectives of Environmental Engineering. Supported by AI tools such as ChatGPT and DeepSeek, the model establishes a teaching framework involving pre-class guidance, in-class inquiry, after-class tutoring, and whole-process assessment. Typical environmental cases, including bisphenol A, per- and polyfluoroalkyl substances, antibiotics, and heavy-metal complexes, are incorporated into the course to promote the integration of organic chemistry knowledge with environmental engineering practice. This model is expected to enhance students' autonomous learning ability, engineering application awareness, and overall competence, providing a new perspective for reforming Organic Chemistry teaching in Environmental Engineering.

1. Introduction

In recent years, large language models represented by ChatGPT and DeepSeek have developed rapidly, and artificial intelligence (AI) is profoundly reshaping teaching models in higher education [1]. The National Education Digitalization Strategy Action and the Outline for Building China into an Education Powerhouse (2024–2035) issued by the Ministry of Education clearly emphasize the need to promote the deep integration of AI with education and teaching, and to build an intelligent, personalized, and open educational ecosystem [2]. Against this background, how to effectively use AI technologies to improve the quality of professional course teaching has become an important direction in higher education reform [3].

Organic Chemistry is one of the core foundational courses in the undergraduate curriculum of

Environmental Engineering. Its main objective is to help students understand the structures, properties, and reaction regularity of organic compounds, thereby laying a theoretical foundation for subsequent courses such as Environmental Chemistry, Water Pollution Control Engineering, Air Pollution Control Engineering, and Environmental Functional Materials [4]. However, long-term teaching practice shows that Organic Chemistry often involves numerous knowledge points, complex concepts, abstract reaction mechanisms, insufficient student interest, and weak connections with professional applications [5]. As a result, many students tend to rely on memorization rather than conceptual understanding, making it difficult for them to connect course knowledge with environmental engineering practice.

Meanwhile, the control of emerging contaminants has become an important component of national ecological civilization construction. Typical organic pollutants, such as bisphenol A (BPA), antibiotics, and per- and polyfluoroalkyl substances (PFAS), are widely present in environmental media, and their environmental behavior, toxic effects, and treatment technologies are closely related to organic chemistry knowledge. Therefore, incorporating environmental pollution control cases into course teaching can not only enhance students' learning interest but also cultivate their ability to apply chemical knowledge to analyze and solve environmental problems.

Based on the above considerations, this paper proposes an AI-empowered blended teaching model for Organic Chemistry tailored to Environmental Engineering students. By constructing an environmental case-driven curriculum system and leveraging the advantages of AI in knowledge acquisition, personalized learning, and intelligent tutoring, this study explores a new pathway for reforming Organic Chemistry teaching in Environmental Engineering.

2. Problems in the Organic Chemistry Course for Environmental Engineering Students

Complex knowledge system and high learning difficulty. Organic Chemistry covers a wide range of functional group properties, reaction types, and reaction mechanisms. For example, nucleophilic substitution reactions (SN1 and SN2), elimination reactions (E1 and E2), radical reactions, and electrophilic aromatic substitution are all highly abstract topics. Students are required to understand molecular structures, electronic effects, reaction conditions, and product selectivity simultaneously, which makes the course challenging [6]. In addition, the knowledge system of Organic Chemistry is highly interconnected. If students do not build a solid foundation in the early stages of learning, they may encounter knowledge gaps in subsequent chapters, thereby affecting their overall learning outcomes.

Insufficient connection between course content and Environmental Engineering. At present, most Organic Chemistry textbooks used in universities are mainly designed for chemistry, chemical engineering, and materials-related majors. Their contents usually focus on organic synthesis and general reaction regularity, whereas Environmental Engineering students are more concerned with pollutant sources, environmental migration and transformation, and treatment technologies. For instance, in the chapter on phenolic compounds, traditional teaching usually emphasizes the acidity of phenolic hydroxyl groups and substitution reactions, but pays limited attention to bisphenol A pollution and its environmental risks. This disconnect makes it difficult for students to recognize the practical value of the course.

Limited learning interest and initiative. Because the course content is abstract and highly theoretical, some students believe that Organic Chemistry is not closely related to their future career development, resulting in insufficient learning motivation. Classroom teaching is still largely dominated by teacher-centered lecturing, with students passively receiving knowledge and having limited opportunities for active inquiry, discussion, and problem-based learning.

Lack of personalized guidance. The traditional class-based teaching model can hardly meet the diverse learning needs of students at different levels. Students with a weak foundation need more targeted support, while those with stronger learning abilities expect further knowledge extension and advanced exploration. However, due to limited time and energy, it is difficult for teachers to provide precise and individualized instruction for every student.

3. Overall Design of the AI-Empowered Blended Teaching Model for Organic Chemistry

The overall framework of the AI-empowered and environmental case-driven blended teaching model for Organic Chemistry tailored to Environmental Engineering students is depicted in Figure 1. Supported by AI-based learning platforms, this model uses typical environmental engineering cases as instructional carriers and takes student competency development as its central objective. It establishes an integrated teaching system covering pre-class guidance, in-class inquiry, and post-class enhancement, thereby promoting the coordinated development of knowledge acquisition, ability cultivation, and value shaping.

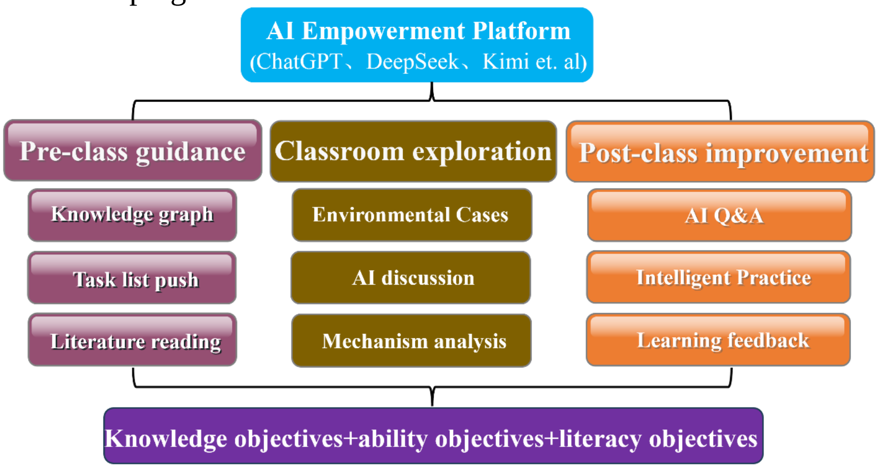

Figure 1: Framework of AI-empowered and environmental case-driven blended teaching model for Organic Chemistry in Environmental Engineering

In the pre-class guidance stage, AI tools such as ChatGPT, DeepSeek, and Kimi are used to support knowledge-map construction, learning-task generation, literature retrieval, and preview guidance. With AI-assisted learning, students can quickly establish a chapter-based knowledge framework, identify key and difficult points in advance, and improve the efficiency of autonomous learning. Meanwhile, teachers can adjust teaching content in a timely manner according to students' preview feedback, thus enabling more targeted instruction.

In the in-class inquiry stage, typical environmental cases are introduced as entry points, and problem-oriented and case-based teaching strategies are adopted. Students are guided to use AI tools to obtain information, analyze problems, and participate in discussions. In this process, teachers act as organizers and facilitators. They evaluate and correct AI-generated responses, help students understand the relationship between Organic Chemistry knowledge and practical environmental engineering problems, and cultivate students' ability to analyze and solve complex engineering problems.

In the post-class enhancement stage, AI platforms are used for intelligent question answering, personalized tutoring, online quizzes, and learning feedback. According to the learning needs of students at different levels, AI can provide differentiated learning support, helping students identify weaknesses, fill knowledge gaps, consolidate what they have learned, and improve their learning abilities. At the same time, teachers can obtain learning behavior data through the online platform and use these data to continuously evaluate and improve teaching effectiveness.

From the perspective of the overall operating mechanism, the three stages of pre-class guidance, in-class inquiry, and post-class enhancement are closely connected and progressively advanced, forming a complete teaching loop. AI technology runs through the entire teaching process and provides intelligent learning support for students, while environmental cases are embedded throughout the course content system to promote the deep integration of professional knowledge and engineering practice. Ultimately, guided by knowledge objectives, ability objectives, and quality-oriented objectives, this model helps students master fundamental theories of Organic Chemistry, improve their ability to analyze environmental problems and conduct engineering practice, and develop green development awareness and social responsibility.

4. Reconstruction of Course Content Driven by Environmental Cases

The proposed reconstruction of the knowledge system for the Organic Chemistry course in Environmental Engineering is illustrated in Figure 2. Traditional Organic Chemistry teaching generally follows the knowledge sequence of "structure–properties–reactions–synthesis". This framework emphasizes the structural features, physicochemical properties, and reaction regularity of organic compounds, and is characterized by strong disciplinary logic. However, it is not sufficiently aligned with the practical needs of Environmental Engineering. As a result, students may acquire fundamental organic chemistry theories but still find it difficult to understand their application value in environmental pollution control and resource recycling.

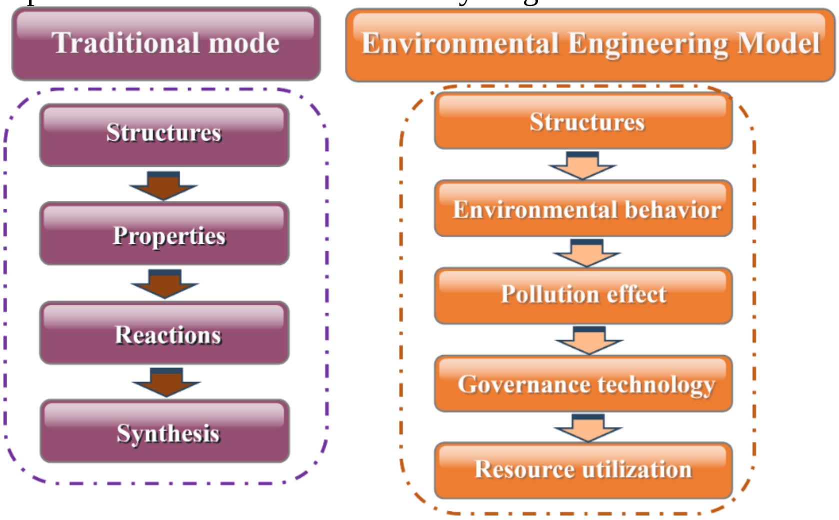

Figure 2: Reconstruction framework of Organic Chemistry knowledge system for Environmental Engineering students

To improve the professional relevance and engineering orientation of the course, this study reconstructs the teaching content based on the training objectives of Environmental Engineering. While retaining the fundamental knowledge system of Organic Chemistry, a new teaching sequence of "structure–environmental behavior–pollution effects–treatment technologies–resource utilization" is proposed. This system closely connects organic chemistry knowledge with the analysis of environmental problems. It guides students to start from molecular structures and gradually understand the migration and transformation of pollutants in the environment, their ecological toxic effects, and the corresponding treatment and resource recovery technologies.

Through this reconstruction, the course content shifts from discipline-centered knowledge transmission to environmental problem-oriented and engineering application-oriented teaching. This not only helps students recognize the practical value of Organic Chemistry knowledge but also cultivates their ability to apply chemical principles to analyze and solve environmental problems.

4.1 Phenolic Compounds: The Case of BPA Pollution

BPA is a typical endocrine-disrupting chemical widely used in the production of polycarbonate plastics and epoxy resins [7]. Its molecular structure contains two phenolic hydroxyl groups connected by an isopropylidene bridge, which endows it with both the characteristic chemical properties of phenolic compounds and strong hydrophobicity.

In the teaching process, students can be guided to analyze: (1) why BPA exhibits high environmental persistence; (2) how the phenolic hydroxyl groups influence its acidity and chemical reactivity; and (3) how hydroxyl radicals attack the aromatic ring during photocatalytic degradation. Through this case, students can better understand the relationship between molecular structure, physicochemical properties, and environmental fate of phenolic pollutants.

4.2 Carboxylic Acids: The Case of EDTA–Heavy Metal Complexes

Ethylenediaminetetraacetic acid (EDTA) is a typical multidentate ligand that can form highly stable complexes with heavy metal ions such as Cu^{2+} and Pb^{2+}. In environmental monitoring, heavy metals in complexed forms are often difficult to detect directly, and decomplexation processes, such as UV-photocatalytic treatment, are required to release free metal ions.

In this section, teachers can guide students to analyze the coordination roles of the carboxyl and amino groups in EDTA molecules and further discuss the application of chelating agents in environmental remediation and resource recovery. This case helps students understand the relationship between carboxylic acid functional groups and coordination chemistry in practical environmental engineering.

4.3 Halogenated Hydrocarbons: The Case of PFAS

PFAS are widely recognized as “forever chemicals” because of their extraordinary chemical stability, which mainly originates from the high bond dissociation energy of the C–F bond. By introducing this case, students can gain a deeper understanding of the structural characteristics of halogenated hydrocarbons and the relationship between chemical bond strength and environmental persistence.

This case also enables students to recognize the challenges associated with emerging contaminant treatment and the importance of developing advanced remediation technologies.

4.4 Aromatic Compounds: The Case of Antibiotic Pollution

Antibiotics commonly contain aromatic rings and multiple functional groups, and their long-term persistence in the environment may induce bacterial resistance [8]. By analyzing the molecular structures of representative antibiotics, students can better understand the structural features and environmental risks of aromatic compounds.

This case can also be extended to discussions on the environmental behavior, ecological risks, and degradation pathways of antibiotic contaminants.

Through the integration of these environmental cases, students are encouraged to establish a clearer understanding of the intrinsic relationship between the molecular structures of organic compounds and their environmental behavior. Such case-based teaching not only strengthens students’ theoretical knowledge but also enhances their ability to connect Organic Chemistry concepts with practical environmental issues.

5. Implementation Pathway of the AI-Empowered Blended Teaching Model

5.1 Pre-Class Stage: AI-Assisted Autonomous Learning and Knowledge Construction

The pre-class stage is designed mainly to address the problems of low preview efficiency and insufficient knowledge preparation in traditional teaching. Teachers can use large language models such as ChatGPT and DeepSeek to establish a three-part preview system consisting of learning task sheets, knowledge maps, and problem chains.

Taking the chapter on phenolic compounds as an example, teachers may first assign the following learning tasks: (1) search for the molecular structure and major applications of BPA; (2) analyze why BPA is regarded as a typical endocrine-disrupting compound; and (3) consider why BPA is difficult to degrade naturally in the environment.

Students then use AI tools to collect preliminary information and organize relevant knowledge. Compared with conventional search engines, AI tools can rapidly generate structured knowledge frameworks and help students build meaningful knowledge networks. For example, students may use AI to construct a knowledge chain of "phenol → bisphenol A → environmental behavior → toxic effects → treatment technologies", thereby achieving knowledge transfer from chemical structure to environmental application. Teachers can review students' preview outcomes through the online platform, identify possible inaccuracies in AI-generated content, and make necessary corrections before class, thus preparing more effectively for classroom teaching.

5.2 In-Class Stage: Environmental Case-Driven Learning and AI-Assisted Inquiry

The classroom implementation process based on AI assistance and environmental case-driven learning is exhibited in Figure 3. This process takes real environmental problems as the entry point, regards students' active inquiry as the core, and uses teacher guidance and AI support as key scaffolds. Accordingly, a closed-loop classroom teaching process is established, consisting of "case introduction–information acquisition–discussion and analysis–correction and improvement–knowledge transfer".

At the beginning of the class, teachers introduce representative environmental pollution cases to stimulate students' learning interest and problem awareness. By connecting abstract chemical knowledge with real environmental engineering problems, students can better clarify the learning objectives and application context of the lesson. After the case is introduced, students use AI tools such as ChatGPT and DeepSeek to retrieve information and organize relevant knowledge. AI can rapidly provide information on pollutant structural characteristics, environmental behavior, toxic effects, and possible treatment technologies, thereby providing a foundation for subsequent analysis.

On this basis, students conduct group discussions and analyses around the key questions proposed by the teacher. Through discussion, students not only deepen their understanding of theoretical knowledge but also improve their teamwork and problem-solving abilities. During the discussion, the teacher plays the role of facilitator and corrector. On the one hand, the teacher identifies and corrects possible inaccuracies or logical deviations in AI-generated information. On the other hand, the teacher guides students to understand the intrinsic relationships among molecular structure and properties, properties and reactions, and reactions and environmental behavior from the perspective of chemical principles, helping them build a systematic knowledge framework.

At the end of the class, the teacher summarizes the results of case analysis and further extends them to more complex environmental engineering problems. Overall, this teaching process is expected to improve students' classroom participation, autonomous learning ability, and comprehensive competence in applying Organic Chemistry knowledge to solve environmental engineering problems.

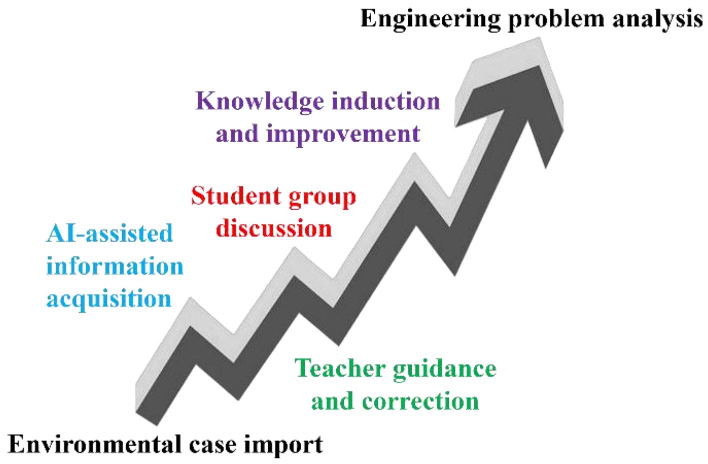

Figure 3: Classroom teaching process based on AI-assisted and environmental case-driven learning

5.3 Post-Class Stage: AI-Based Personalized Tutoring and Competency Enhancement

In the post-class stage, AI is employed to provide personalized learning support and further strengthen students' understanding of course content. Students can raise questions to AI tools at any time, such as: "Why are PFAS difficult to degrade?", "What are the fundamental differences between SN1 and SN2 reactions?", and "How do hydroxyl radicals attack the aromatic ring during the photocatalytic degradation of BPA?"

AI tools are able to provide instant feedback, which helps students address learning difficulties in a timely manner and improve their understanding of complex concepts. Meanwhile, teachers can analyze students' learning trajectories through data recorded on the online learning platform, allowing them to adjust teaching strategies and optimize instructional content accordingly.

6. Risks and Regulations of AI Application

Although AI provides new opportunities for curriculum reform, its application also involves certain risks.

(1) AI hallucination

Large language models may generate inaccurate or even misleading information. For example, incorrect interpretations or unreasonable deductions may occur when explaining organic reaction mechanisms. Therefore, teachers must assume the responsibility of reviewing and verifying AI-generated content to prevent students from uncritically accepting incorrect information.

(2) Academic integrity

Some students may directly copy AI-generated content to complete assignments. To address this problem, it is necessary to establish clear AI usage guidelines, citation requirements, and process-based assessment systems to ensure students' genuine participation in the learning process.

(3) Over-reliance

AI should be regarded only as an auxiliary learning tool rather than a substitute for independent thinking. Teachers should encourage students to critically evaluate AI-generated answers instead of simply accepting them.

7. Construction of the Course Evaluation System

The diversified evaluation system designed for the AI-empowered blended teaching model is demonstrated in Figure 4. Unlike the traditional assessment approach, which mainly relies on final examinations, this system emphasizes a combination of formative assessment and summative assessment, aiming to comprehensively evaluate students' knowledge mastery, learning process, and practical application abilities.

In this evaluation framework, the part of classroom participation accounts for 15% of the total score, mainly assessing students' engagement in classroom discussions, case analyses, and interactive activities. This component encourages students to actively participate in the learning process and strengthens their initiative in knowledge exploration.

The part of Case analysis reports account for 20%, focusing on students' ability to integrate Organic Chemistry knowledge with environmental engineering problems. Through analyzing typical cases such as BPA pollution, PFAS degradation, and EDTA-heavy metal complexes, students are expected to demonstrate their capability in applying theoretical knowledge to practical environmental issues.

The part of AI learning records contribute 10% to the final grade. This part evaluates students' pre-class preparation, post-class interactions with AI tools, and independent knowledge construction. By incorporating AI-assisted learning performance into the evaluation system, students are encouraged to make effective and responsible use of intelligent tools throughout the learning process.

The part of Stage tests account for 25% and are designed to assess students' understanding of key concepts, reaction mechanisms, and problem-solving skills at different stages of the course. This helps teachers identify students' weaknesses and adjust teaching strategies in a timely manner.

The part of final examination, which makes up 30% of the total score, remains an important summative assessment tool. It mainly evaluates students' overall mastery of Organic Chemistry knowledge and their ability to comprehensively analyze and solve complex problems.

Overall, this diversified evaluation system reflects the principles of outcome-based education by emphasizing the integration of knowledge, ability, and quality. It not only promotes students' continuous learning and active participation but also better aligns with the teaching objectives of cultivating environmental engineering professionals with strong theoretical foundations and practical competencies.

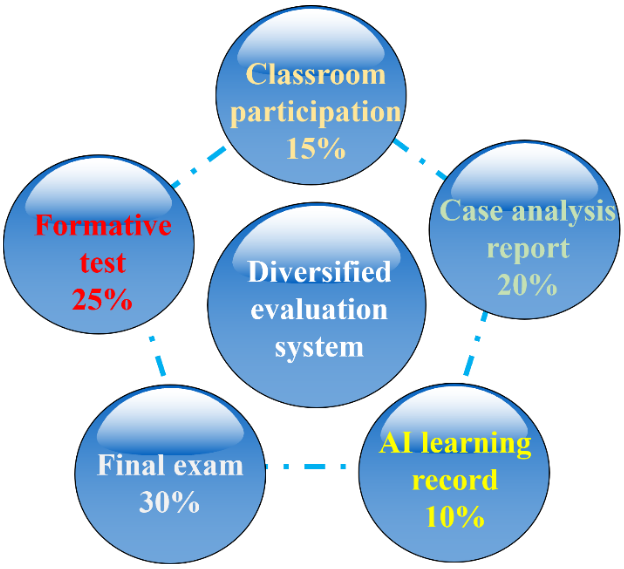

Figure 4: Composition and Weight Distribution of the Course Evaluation System

8. Expected Outcomes and Innovations

Through the proposed teaching process, the following outcomes are expected: improving students' learning interest and classroom participation; enhancing their autonomous and lifelong learning abilities; promoting the integration of Organic Chemistry knowledge with Environmental Engineering education; cultivating students' ability to analyze complex environmental problems; and improving the achievement of course objectives.

The innovations of this study are mainly reflected in three aspects. First, the model adopts a dual-driven approach that integrates AI empowerment with environmental case-based teaching. It moves beyond conventional AI-assisted instruction by deeply embedding AI tools into discipline-specific Environmental Engineering cases. Second, it emphasizes the integration of research and teaching. Research outcomes related to photocatalytic degradation of bisphenol A, decomplexation of EDTA–heavy metal complexes, and emerging contaminant treatment are introduced into classroom teaching, thereby promoting the coordinated development of scientific research and undergraduate education. Third, it constructs a whole-process intelligent teaching system, forming a complete closed loop of "pre-class guidance–in-class inquiry–post-class enhancement–evaluation feedback".

9. Conclusions

To address the problems of abstract knowledge, insufficient professional relevance, and limited personalized guidance in the Organic Chemistry course for Environmental Engineering students, this paper proposes an online–offline blended teaching model that integrates AI empowerment with environmental case-driven learning. This model takes full advantage of AI in knowledge acquisition, personalized learning, and intelligent tutoring, and incorporates typical environmental cases such as bisphenol A, PFAS, antibiotics, and EDTA complexes throughout the teaching process. In this way, it promotes the deep integration of Organic Chemistry knowledge with Environmental Engineering applications. In future teaching practice, the proposed model will be further implemented, validated, and evaluated. The course system will be continuously optimized to provide support for cultivating innovative talents in Environmental Engineering.

Acknowledgement

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