



Artificial Intelligence-Enhanced Project-Based Learning: A Novel Teaching Model for Inorganic and Analytical Chemistry Courses

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Abstract. This paper explores the application and effectiveness of artificial intelligence (AI) technology in Project-Based Learning (PBL) teaching for the course Inorganic and Analytical Chemistry. By analyzing the challenges faced in traditional teaching, such as abstract concepts, low student engagement, and insufficient personalized guidance, the study proposes an integrated approach combining AI with PBL. Using the "acid-base balance" unit as an example, the article details the practical applications of AI in curriculum design, process guidance, learning support, and teaching evaluation, including virtual simulation, adaptive learning, intelligent Q&A, and data analysis. Results demonstrate that AI significantly enhances students' learning interest, conceptual understanding, and comprehensive abilities, while also fostering critical thinking and interdisciplinary competence. The paper also addresses challenges in AI-enabled education and suggests future directions for development.

Keywords: Artificial Intelligence, Project-Based Learning, Inorganic Chemistry, Analytical Chemistry

1 Introduction

With the rapid advances in artificial intelligence technology, the field of education is undergoing an unprecedented digital transformation. The deep integration of AI technology with teaching and learning has become a key driver of educational innovation, particularly in traditional natural science disciplines such as chemistry^[1]. AI is not only transforming research paradigms in chemistry but also bringing revolutionary changes to chemical education^[2].

As a fundamental course for majors including chemistry, chemical engineering, materials science, biology, and environmental science, Inorganic and Analytical Chemistry is characterized by its abstract concepts, complex knowledge structure, and strong practical emphasis^[3]. Under traditional teaching modes, this course often faces issues such as low student engagement, a disconnect between theoretical knowledge and experimental or practical application, and a lack of personalized guidance tailored to individual differences^[4, 5].

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Artificial intelligence-assisted Project-Based Learning (PBL) offers new pathways to address these challenges. Within the PBL framework, AI can enhance intuitive understanding of abstract concepts through intelligent scenario design, provide adaptive learning support tailored to students' varying progress and cognitive styles, and enable continuous diagnosis and feedback on learning progress via data-driven process evaluation^[6, 7]. These applications not only mitigate the limitations of traditional instruction but also further enhance the targeting, interactivity, and effectiveness of PBL.

This paper aims to explore how AI technology empowers the PBL teaching model in Inorganic and Analytical Chemistry, analyze practical cases, summarize outcomes and challenges, and outline future development directions, with the goal of providing insights and references for innovation in chemical education. Theoretical Integration of Artificial Intelligence and the PBL Teaching Model.

2 Theoretical Integration of Artificial Intelligence and the PBL Teaching Model

2.1 Core Elements and Common Issues of the PBL Model.

PBL (Project-Based Learning) is a student-centered teaching approach that emphasizes comprehensive project activities through which students explore authentic, complex problems and ultimately produce demonstrable outcomes^[8]. Its key components include driving questions based on real-world issues, student-led inquiry, discussion and reflection followed by revision, and public presentation of results^[9]. In chemistry education, PBL helps students establish connections between disciplinary knowledge and practical application, while fostering scientific thinking and problem-solving skills. However, traditional PBL implementation often faces challenges such as limited scenario design, untimely guidance during the process, and highly subjective evaluation.

2.2 The Enhancing Role of AI Technology in PBL Teaching.

Artificial intelligence technology provides comprehensive support for PBL instruction, significantly enhancing its educational value and practical effectiveness. Firstly, generative AI systems such as DeepSeek and ChatGPT, with their powerful natural language processing and content generation capabilities, can assist teachers in collecting, organizing, and generating authentic contextual problems for implementing PBL.

Secondly, knowledge graph technology and AI systems based on adaptive learning algorithms can interrelate fragmented knowledge points through graphical representations, forming a structured knowledge system. By analyzing students' learning behaviors and cognitive levels, these systems offer real-time customized learning paths and resource recommendations.

Furthermore, AI-powered assistants can provide real-time Q&A and guidance, addressing the limitation of instructor availability during PBL processes. In the final evaluation stage of a project, AI technology enables more objective and comprehensive

assessment methods through data collection and analysis of the entire student project process.

Figure 1 illustrates an intelligent teaching system composed of a three-layer architecture. The foundational support layer integrates large language models, adaptive learning algorithms, and structured knowledge graphs, providing the core AI capabilities for instruction. The core functional layer corresponds to the three stages of PBL pedagogy—pre-class, in-class, and post-class—delivering specific functions such as case generation, real-time guidance, and automated evaluation. The application layer directly serves both teachers and students. The entire process forms a closed-loop data flow, wherein the system continuously refines recommendation and evaluation models by collecting teaching data.

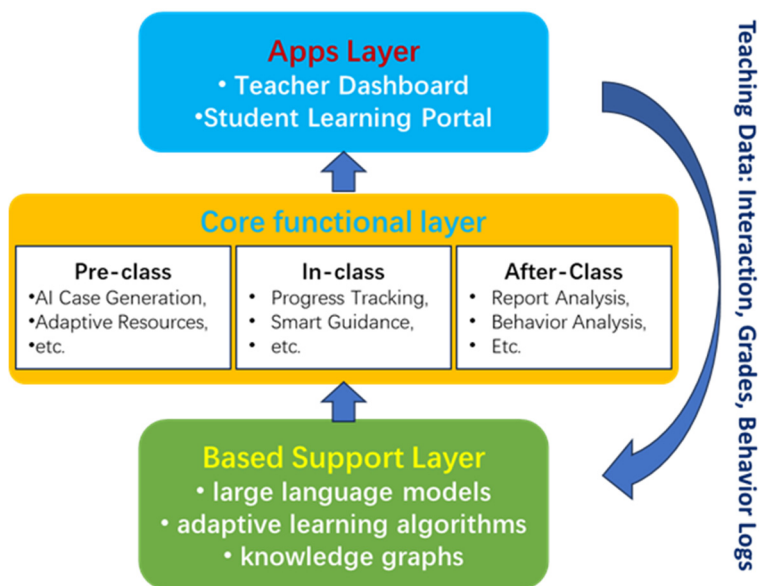


Fig. 1. Architecture Diagram of the AI-Enhanced PBL Teaching System.

3 Practical Application of AI Technology in PBL Teaching of Inorganic and Analytical Chemistry

The following takes the "acid-base balance" chapter in the Inorganic and Analytical Chemistry course offered for medical students as an example to introduce the specific application of AI technology in PBL teaching.

3.1 PBL-Based Instructional Design

3.1.1 Teaching Philosophy and Objectives. Based on the characteristics of the teaching audience (undergraduate medical students), this lesson uses clinical or physiological problems as anchors to guide students to explore how the human body skillfully uses chemical principles to maintain life homeostasis. By playing the role of "medical consultants," students deeply understand buffer systems and connect abstract formulas with vivid life processes. Through independent learning and discussion reflection, the following teaching objectives are achieved:

1. Knowledge level: Master the acid-base proton theory, the composition and working principle of buffer solutions.
2. Ability level: Cultivate evidence-based clinical reasoning ability, correctly calculate the pH of buffer solutions, and discuss the direction of acid-base reactions based on chemical equilibrium principles.
3. Literacy level: Recognize that chemistry is the foundation of life sciences, exercise teamwork ability, and cultivate scientific ethics and humanistic care spirit.

3.1.2 PBL Driving Question Design. First, design a clinical-colored and exploratory research project: "How to diagnose a patient with suspected acid-base balance disorder and propose theoretical treatment suggestions?" Then, break down the research project into several sub-questions (group tasks) to guide students to solve them one by one.

1. Theoretical basis inquiry

Question 1: "What are the main buffer systems in the human body? Which one is the most important in the blood? What is its chemical composition (conjugate acid-base pair)?" (Knowledge point: acid-base theory and buffer systems)

Question 2: "What roles do the lungs and kidneys play in maintaining body fluid pH homeostasis? What are the chemical principles behind their functions?" (Knowledge point: working principle of buffer solutions)

2. Case analysis and calculation

Question 1: "What is arterial blood gas analysis (ABG)? What do pH, $p_a(\text{CO}_2)$ (partial pressure of carbon dioxide), and HCO_3^- (bicarbonate) in an ABG report represent chemically?" (Knowledge point: relationship between clinical diagnostic indicators and acid-base balance)

Question 2: Given a diabetic patient with $\text{pH}=7.25$, $[\text{HCO}_3^-]=16$ mmol/L, $p_a(\text{CO}_2)=35$ mmHg. Calculate the $[\text{H}^+]$ concentration in the case and verify the pH value. (Knowledge point: calculation of buffer solution pH)

3. Treatment method suggestions

Question 1: For the above case, what are the clinical treatment principles? What drugs might be used? What are their chemical components? How do they react in the body? (Knowledge point: application of acid-base balance)

Question 2: "Why can't treatment be too aggressive? How is this related to the concept of 'buffer capacity'?" (Knowledge point: buffer capacity and titration curve)

3.1.3 Teacher's Role and Activity Design. As a case designer, the teacher needs to design clinically meaningful cases before class that can cover core knowledge points. Simultaneously, they need to create and collect courseware, teaching videos, research papers, reference materials, etc., related to the cases and publish them on the teaching platform in advance for students to consult and refer to at any time.

During class, as a facilitator, the teacher should give problem scaffolds timely based on group discussion progress to help students advance the project according to plan. For example, during group discussions, by asking questions like: "This patient's pH is low. Is it too much acid or too little base? How can you tell?" guide students to establish connections between diagnostic indicators and teaching content.

Secondly, the teacher should also conduct "mini-lectures" duly based on the class progress, focusing on explaining course difficulties. For example, before students perform case analysis calculations, the derivation and physical meaning of the Henderson-Hasselbalch (H-H) equation should be explained, and the method for calculating buffer solution pH should be introduced.

Furthermore, the teacher should act as an AI usage coach, guiding students on how to ask AI questions to obtain high-quality answers. For example, during the discussion of question 2 in the basic theory inquiry, students might initially struggle to find a good entry point. The teacher can then guide students to start from the "main functions of the lungs and kidneys," find the corresponding chemical substances " CO_2 and H_2O ," and then transform the question into "the influence of CO_2 or H_2O on the pH of body fluid (buffer solution)," etc.

3.1.4 Teaching Evaluation and Feedback. PBL teaching evaluation usually includes two parts: process evaluation (60%) and summative evaluation (40%). Process evaluation focuses on students' performance, participation, and the phased objectives during the project inquiry process. Summative evaluation focuses on the final outcome of the project, testing students' comprehensive ability to integrate knowledge, solve problems, and perform clinical reasoning. Specific evaluation content and scoring criteria are shown in Table 1 and Table 2.

Table 1. Process Evaluation Items and Scoring Methods.

Evaluation Dimension	Evaluation Content and Method	Proportion
Group Discussion & Collaboration	Teacher & peer eval: Based on speech quality, question depth, discussion facilitation, and teamwork.	20%
Calculation Process & Results	Submit calculation docs: Showcasing steps, formula use, and results.	20%
Stage Task Completion	Group conclusions: Scored by teacher for accuracy and logic.	20%

Table 2. Summative Evaluation Items and Scoring Methods.

Evaluation Item	Evaluation Content and Method	Proportion
Final Diagnostic Report	The group submits: 1. Etiologic & diagnostic analysis	20%

	2. Calculation process & conclusions (key: result accuracy)	
	3. Treatment plan with chemical principles Presentation (10min + 5min Q&A):	
Calculation Process & Results	1. Clinical reasoning logic	15%
	2. Explanation of results & diagnosis	
	3. Teamwork & response quality	
Stage Task Completion	Individual Reflection (~300 words):	
	1. AI's role in the project	5%
	2. New insights into chemistry-medicine application	

3.2 Specific Application of AI Tools in Various Links of PBL Teaching

3.2.1 Ways AI Assists Teachers in Conducting PBL Teaching. 1. Course Design and Content Generation (Pre-class Preparation)

AI can help teachers quickly obtain a large number of high-quality case libraries, and modify them according to teaching difficulty, saving a lot of lesson preparation time. For example, when designing calculation cases, you can directly ask AI to generate 5 simulated cases about acid-base balance disorders, each containing different pH, $p_a(\text{CO}_2)$, and HCO_3^- values, corresponding to different types such as respiratory acidosis and metabolic alkalosis. Moreover, AI can provide standard answers and analysis in the meantime.

AI can help teachers "translate" complex content into materials that are more in line with students' current cognitive levels, acting as a teaching assistant to achieve teaching students according to their aptitude. For example, when creating personalized learning materials, you can ask AI from the student's perspective: "My students are freshmen chemistry majors with weak physiology knowledge. Please use easy-to-understand language and analogies to explain the role of the lungs and kidneys in acid-base balance."

Furthermore, AI can help teachers quickly build a clear, fair, and multi-dimensional evaluation system, making learning objectives clearer. For example, when designing scoring criteria for group presentations, you can ask AI to design a scoring rubric. The evaluation dimensions include chemical concept accuracy, AI tool usage level, clinical logical reasoning ability, teamwork, and report presentation—four dimensions, each divided into 4 levels.

2. Teaching Process Management and Differentiated Instruction (In-class Implementation)

In the PBL teaching process, effectively managing class progress is crucial for the smooth implementation of projects. However, in classrooms with multiple groups, teachers often struggle to monitor the real-time progress of all groups simultaneously. To address this challenge, instructors may preset different discussion durations based on the complexity of the questions before the discussion begins. Once a group begins discussing a particular question, the AI system initiates real-time monitoring. If the discussion time exceeds the preset limit, the system automatically alerts both the teacher and students. This allows students to proactively adjust their discussion pace, while teachers can intervene in a timely manner and provide targeted guidance, thereby ensuring that the project advances according to schedule.

AI can also become the teacher's "question bank," helping teachers guide student thinking in a more professional and effective way, improving facilitation skills. For example, when a teacher discovers a group in difficulty but doesn't know how to give guiding questions. The teacher can ask AI for help. For example, the teacher can ask: "This group cannot understand the relationship between HCO_3^- and CO_2 . Please give me a few inspiring questions." AI might reply: "You can ask: 'If we regard blood as a buffer solution, what does CO_2 correspond to? What does HCO_3^- correspond to?' or 'Faster breathing, does it increase acid or decrease acid? How will this change affect the equilibrium?'"

AI can also help teachers achieve efficient differentiated instruction. For example, due to differences in student foundations, group progress often varies during class discussions. At this time, the teacher can quickly ask AI to generate "extension challenge tasks" (e.g., "Research the chemical mechanism of lactic acidosis") or "basic consolidation exercises" (e.g., "Additional buffer solution pH calculation exercises") and instantly push them to groups with different progress levels, easily achieving layered teaching.

3. Homework Assessment and Feedback (Post-class Evaluation)

AI can help teachers with the first round of homework grading and feedback, freeing teachers from heavy repetitive labor, allowing them to focus on evaluating the innovation, depth, and logical rigor in student reports that AI cannot judge. For example, after a group completes case analysis calculations, the teacher can use AI to quickly analyze whether their H-H equation calculation is correct, thus ensuring the progress of subsequent case analysis.

Furthermore, AI can act as a "teaching consultant," providing teachers with objective analysis and suggestions, promoting continuous improvement of teaching methods. For example, after completing a round of teaching, the teacher can send the PBL course syllabus and post-class records to AI, asking it to analyze potential problems and suggest how to optimize the next teaching design.

3.2.2 Ways AI Assists Students in Participating in PBL Learning. Throughout the PBL teaching process, AI tools are deeply integrated into various links, playing diverse roles according to different stage tasks, providing students with comprehensive and personalized support.

1. Problem Analysis and Knowledge Retrieval

At this stage, student groups exhibit preliminary discussion around the core question "How to diagnose acid-base balance disorders," identifying knowledge gaps. AI mainly plays the role of a research assistant. Students can use large language models like ChatGPT or DeepSeek to quickly query and sort out interdisciplinary knowledge. For example, they can ask AI: "Explain respiratory acidosis using chemical principles" or "What is the chemical reaction equation for sodium bicarbonate correcting metabolic acidosis?". AI can quickly provide clear explanations, case summaries, or even comparison tables, helping students efficiently build a knowledge background connecting chemistry and physiology, laying the foundation for subsequent inquiry.

2. Independent Inquiry and Conceptual Learning

When students need to deeply understand core chemical concepts (such as the relationship between pH and pKa, buffer mechanism), AI becomes as a never-tiring private tutor. Students can watch customized videos on platforms like Rain Classroom or XuetangX, or use PhET interactive simulation software to dynamically simulate the acid-base titration process, intuitively observing changes in the buffer curve. AI-driven adaptive learning systems can intelligently push practice materials suitable for their current level based on students' answering situations, effectively fill the knowledge gaps up, ensuring every student firmly masters the basic principles.

3. Critical Thinking and Optimization

Once students develop initial diagnostic and treatment ideas, they are encouraged to critically evaluate and refine their proposals. In this context, AI can assume the role of an “experienced consultant”. By engaging with tools such as DeepSeek through role-playing prompts—for instance, “As a senior clinician, what potential risks would you identify in this treatment strategy?”—students encounter challenges from diverse perspectives. Such interactions help uncover limitations and unnoticed aspects of their reasoning, promoting deeper, more rigorous, and comprehensive thinking, and ultimately fostering advanced critical thinking abilities.

4. Outcome Production and Reporting

During the final output phase, AI serves as a productive design assistant. Learners can use AIGC applications to quickly transform key insights from their analytical reports into clear, polished slide frameworks and visual aids. These technologies considerably raise the professionalism and efficiency of outcome production, allowing students to dedicate more attention to refining core arguments and preparing for delivery.

In summary, AI tools are woven throughout the entire PBL process. Evolving from an initial source of information to a facilitator of skills, a stimulator of critical thought, and a catalyst for efficiency, AI comprehensively supports students as they engage with authentic, complex problems and develop deeper learning competencies.

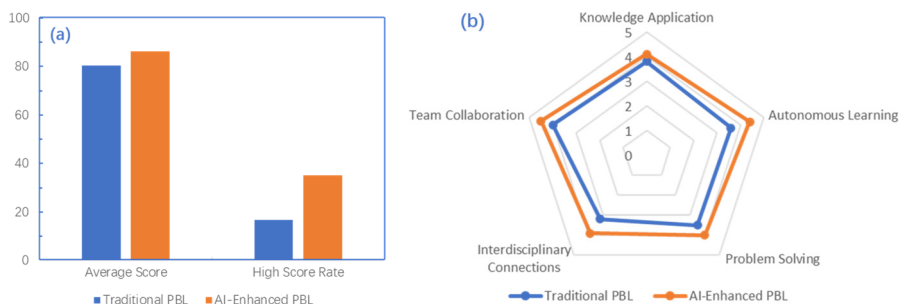


Fig. 2. (a). Comparison of Unit Test Score Distributions Between Traditional PBL and AI-Enhanced PBL Classes. (b) Radar Chart Comparing Students' Comprehensive Competencies Based on Teacher Evaluation.

4 Conclusion

The integration of artificial intelligence and Project-Based Learning (PBL) has brought innovative energy to the teaching of Inorganic and Analytical Chemistry, effectively addressing many of the limitations inherent in traditional instructional approaches. As shown in Fig. 2(a), a comparison of unit test scores on "acid-base balance" was conducted between two parallel classes: one taught using traditional PBL (control group) and the other taught using AI-enhanced PBL (experimental group). The average score of the experimental group increased from 78.5 to 86.2 (an improvement of 9.8%), and the high-score rate (>90 points) significantly increased from 16.7% to 35.0%. The results indicate that AI-driven personalized support and concept visualization effectively enhanced students' comprehension and mastery of complex knowledge points. From the radar chart in Fig. 2(b), it is evident that after the implementation of AI-supported PBL instruction, students demonstrated significant improvements in knowledge application, autonomous learning, problem-solving, and interdisciplinary collaboration skills.

However, the implementation of AI-assisted PBL still faces several challenges in practice, including students' over-reliance on AI tools, varying levels of digital literacy among instructors, substantial resource investment requirements, and the lack of unified evaluation standards. Addressing these issues will require collaboration among educators, technical experts, and policymakers—through strategies such as enhancing teacher training, increasing investment in digital infrastructure, strengthening school-enterprise cooperation, and establishing clear guidelines and standards.

Looking ahead, as artificial intelligence continues to advance and its educational applications deepen, AI-supported PBL teaching is expected to become more intelligent, responsive, and efficient. It will better facilitate the development of students' comprehensive competencies and innovative capacities, thereby providing strong support for education in chemistry and related fields.

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