Teaching Reform and Innovation of Physical Chemistry Course under the Background of Artificial Intelligence

Jinxiao Zhang*, Xiaojun Kuang, Yongping Liu

College of Chemistry and Bioengineering, Guilin University of Technology, Guilin, 541006,China
**Corresponding author:jxzh@glut.edu.cn*

Abstract: *This work explores the reform of the Physical Chemistry course in regional universities under the background of artificial intelligence (AI). Taking Guilin University of Technology in China as a case study, the course is redesigned to address issues such as weak local relevance, insufficient interdisciplinary integration, low digitalization, and limited practical application. Teaching content is reconstructed using knowledge graphs to incorporate regional pillar industries such as new energy vehicles and non-ferrous metals. A discipline–technology–industry matrix is established, integrating AI tools including machine learning and intelligent simulation software. A smart teaching platform is developed to support personalized learning and competency-based assessment. Furthermore, an industry–education data-sharing mechanism is introduced to transform theoretical knowledge into engineering capabilities. These reforms enhance students' professional competencies and contribute to the development of high-quality engineering professionals aligned with regional economic needs.*

Keywords: *artificial intelligence; physical chemistry; teaching reform; regional universities*

1. Introduction

The Fourth Industrial Revolution is reshaping global scientific and industrial landscapes, powered by rapid advances in artificial intelligence (AI), Big Data, and the Internet of Things [1-3]. In response to this technological shift and to align with national strategies such as the Belt and Road Initiative and Made in China 2025, China's Ministry of Education has launched a series of initiatives—namely the Fudan Consensus, Tianjin Action, and Beijing Guide—to drive the development of emerging engineering education [4-5]. These initiatives focus on cultivating "three-strong" engineering professionals with robust practical competence, high innovation potential, and strong professional competitiveness. As AI technologies continue to evolve, they are providing powerful tools and fresh momentum for deep and systematic reform in education.

Physical chemistry is a foundational course in many engineering and science disciplines at regional universities—spanning energy, chemical, materials, environmental, bioengineering, and pharmaceutical studies[6-7]. It encompasses core theoretical domains such as thermodynamics, kinetics, and electrochemistry, and its instructional quality plays a critical role in shaping students' abilities in analytical modelling, quantitative reasoning, and practical application. These competencies are essential for addressing real-world challenges in process optimization, innovative chemical design, sustainable energy development, environmental engineering, and biomedical technology. Yet, traditional approaches to teaching physical chemistry reveal limitations in both teaching resources and methods, which severely impede the development of the multifaceted, interdisciplinary skills demanded by the emerging engineering era. The emergence of generative AI platforms such as DeepSeek and ChatGPT offers a vital avenue for transforming the course towards intelligent, personalized learning aligned with Industry 4.0 needs.

2. Current Status and Challenges of Physical Chemistry in Regional Universities

Regional universities bear the dual mission of nurturing applied, high-quality professionals and fostering local economic development. Nevertheless, constraints in resource allocation and disparities in regional development have led to shortcomings in four core dimensions of the physical chemistry curriculum: limited integration of regional characteristics, weak interdisciplinary synergy, delayed digital-intelligence upgrades, and insufficient practical engineering transformation. The rapid advancement of AI offers new solutions, enabling intelligent teaching restructuring and targeted competence building to enhance educational effectiveness and student development through synergistic integration.

The physical chemistry curriculum in regional universities demonstrates insufficient integration of regional characteristics. As a core subject underpinning various engineering disciplines, the traditional physical chemistry curriculum often emphasizes theoretical completeness and universality at the expense of embedding local industrial features and institutional strengths. It lacks dynamic adaptation to regional economic strategies and fails to incorporate indigenous industry case studies, resulting in a gap between theoretical training and local enterprise demands. Consequently, graduates are ill-prepared to support technical innovation in local industries.

Another challenge lies in the curriculum's lack of meaningful interdisciplinary synergy with emerging scientific and engineering fields. Amid China's shift to intelligent manufacturing, there is a growing demand for multidisciplinary professionals. However, the current curriculum often treats connections with materials science, environmental engineering, etc., as superficial. Integrating modern technological tools—such as machine learning for process optimization or molecular simulation for material design—is rare. Teaching remains dominated by traditional trial-and-error methods, lacking reflection of intelligent manufacturing paradigms. This disconnect impedes students from developing systemic thinking and innovative problem-solving capabilities in practical projects like new-energy materials and green processes.

A further obstacle is the lag in integrating digital and intelligent technologies into the teaching framework. Digitization of the curriculum faces structural bottlenecks: teaching resources (slides, knowledge graphs, case libraries, test banks) are updated infrequently and lag new technological developments; classrooms remain largely teacher-centered; adaptive systems based on learning analytics are absent; intelligent teaching platforms are under-utilized; real-time feedback and adaptive fixes are missing. A 2024 report on higher education informationization revealed that only 42 % of regional universities have deployed intelligent teaching systems in foundational courses related to science, engineering, and technology. This low interactivity and weak feedback model conflicts sharply with the modern educational ethos of student-centeredness, cross-domain integration, and innovation, severely restricting students' capacity for self-driven inquiry and creativity.

Finally, the curriculum struggles to effectively translate theoretical knowledge into engineering practice relevant to local industries. The transition to emerging engineering education highlights the need for applied training. Nonetheless, the physical chemistry syllabus is overloaded with classical theoretical derivations, lacking exercises that align thermodynamics or kinetics with regional industry cases—for instance, refining Aluminum processes in Guangxi or designing thermal management for batteries. Assessment is dominated by homework (60 %) and final exams (30 %), with formative evaluation of practical problem-solving under 10 %. While 83 % of regional universities have partnerships with enterprise, only 12 % of teaching includes real engineering case studies. For example, graduates may fluently recite the Nernst equation, yet cannot apply it to optimize electrolyte formulations for high-humidity climates. This theoretical-practical divide hinders students from diagnosing process inefficiencies or designing industrial adsorption materials, contravening the objectives of emerging engineering education.

3. AI-Enabled Reform and Innovation in the Physical Chemistry Curriculum

Drawing on the Physical Chemistry course at Guilin University of Technology as a practical case, this research systematically explores pathways to deeply integrate AI, thereby addressing the four aforementioned challenges of regional relevance, interdisciplinary integration, digital intelligence, and applied transformation. The proposed four-dimensional "AI + regional industry" model aligns closely with Guangxi's industrial revitalization strategies and provides a replicable framework for curriculum reform and innovation at regional universities (Figure 1).

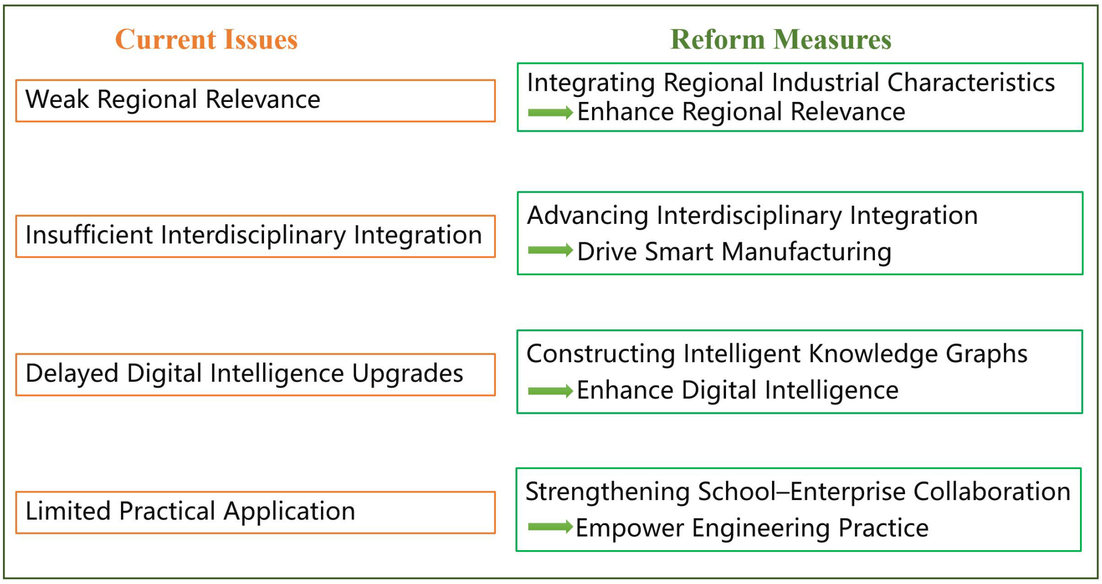

Figure 1. Schematic diagram of teaching reform and innovation of physical chemistry course.

3.1 Integrating Regional Industrial Characteristics to Enhance Local Relevance

As a data-driven analytical tool, AI empowers the reconfiguration of curricula with revolutionary precision.

As a data-driven analytical tool, AI empowers the reconfiguration of curricula with revolutionary precision. By leveraging AI-augmented educational platforms—such as Zhihuishu, Rain Classroom, Superstar Learning, DeepSeek and ChatGPT—educators can upload large volumes of course materials, including textbooks, lecture slides, teaching plans, and historical case libraries. These platforms employ large language models to automatically generate interactive knowledge graphs that map conceptual linkages, skill-development pathways, and value orientations. Without requiring programming skills, teachers can engage in natural language interactions to visualize concept trees and logic maps, dynamically adapting content to local industry needs. For instance, AI can analyze recent technology upgrade reports from Guangxi Aluminium Branch to extract key thermodynamic parameters from electrolysis processes, and generate visual modules for phase equilibrium teaching.

The curriculum is closely aligned with Guangxi's new energy vehicle initiative under the "Pinnacle Action" plan. In the electrochemistry unit, students model the Gibbs free energy and energy density of CATL's CTP 3.0 Kirin battery; design temperature-dependent voltage decay simulations based on canal freight conditions related to the Pinglu Canal project; and analyze ion migration and thermal runaway using BYD blade battery puncture test data. These are integrated with a university-level "Green Energy Innovation Challenge" where students design electrode modifications through comprehensive experiments. In response to Guangxi's strengths in non-ferrous metallurgy, a dedicated module allows students to build dynamic multicomponent phase diagrams—such as for tin-lead separation using AI-trained models based on data from the Nandan tin mining region. Another project, reflecting Guilin University of Technology's institutional spirit of application-oriented education, engages students in optimizing energy efficiency in aluminium electrolysis by applying the first law of thermodynamics to calculate heat loss compensation in electrolytic cells. In agricultural processing, local resources such as sugar and tea industries are deeply embedded. The curriculum incorporates entropy change analyses from the triple-effect evaporator systems used in sugarcane molasses refining, to illustrate Carnot cycle applications in waste heat recovery. It also engages students in modelling moisture diffusion kinetics during tea fermentation and drying, helping them connect surface chemistry with food technology innovation.

3.2 Advancing Interdisciplinary Integration to Drive Smart Manufacturing

To dissolve traditional disciplinary boundaries, a three-dimensional integration framework—linking discipline, technology, and industry—is established through the lens of AI-enabled education, fostering the integration of cross-disciplinary knowledge and cultivating intelligent manufacturing capabilities to meet the demands of regional industrial upgrading.

To promote cross-disciplinary fusion, the curriculum systematically blends physical chemistry with materials science, environmental engineering, and pharmaceutical disciplines. In the surface-chemistry module, students investigate the anodization process used by Guangxi Nannan Aluminum, analyzing the formation of alumina nanopores to understand how voltage gradients influence pore morphology and barrier-layer growth. This guides learners in connecting microscopic structure to macroscopic function. In environmental governance, a comprehensive case study on cadmium-ion adsorption by activated carbon–TiO_2 composites addresses the heavy-metal pollution in the Hongshui River Basin of Guangxi. Students apply interfacial chemistry principles and precipitation-dissolution equilibria to design graded precipitation solutions, developing multi-disciplinary problem-solving abilities. The chemical kinetics module incorporates pharmaceutical contexts by modelling the degradation of anti-tumor drug microcapsules, allowing students to quantify the influence of surfactant concentration on release dynamics and appreciate the application of reaction kinetics in biomedical systems.

To enhance technological integration, intelligent tools such as machine learning and molecular simulation are embedded in core modules to modernize research training. In the electrochemistry module, students are guided through AI-powered prediction of lattice distortions in lithium–nickel–manganese oxide cathodes, followed by first-principles calculations of ion-migration energy barriers. In a surface chemistry course, students replicate findings from an advanced study in J. Am. Chem. Soc [8]. that guides them in quantitatively determining surface–adsorbate properties. This is achieved through vibrational spectroscopy of CO sorption on bimetallic Au/Ag—a key intermediate in CO_2 reduction reaction catalysts—using interpretable machine learning. The work bridges physical chemistry, data science, and computational methods. A battery-health diagnostics module introduces AI-driven life-prediction models based on voltage relaxation and internal resistance data, familiarizing students with data- driven approaches to scientific inquiry and predictive maintenance.

To align with industrial applications, the curriculum incorporates real-world smart manufacturing scenarios to enhance application-oriented teaching. A comprehensive case study on intelligent control is introduced in the reaction kinetics section, drawing from the hydrogen fuel-cell production lines of Yuchai Group. Students construct a coupled model of temperature, pressure, and conversion rate, and apply PID control algorithms to dynamically optimize the synthesis conditions of proton exchange membranes—e.g., when reactor temperature fluctuates by ±5 °C, the system auto-adjusts coolant flow to maintain optimal reaction pathways. In electrolyte synthesis, real-time monitoring of current density and ion-migration rates enables students to fine-tune electrode spacing and cell voltage parameters. The phase-equilibrium unit integrates crystallization data from Guangxi's sugar industry, applying machine-learning algorithms to develop supersaturation prediction systems that accurately control crystal-size distribution, linking thermodynamics with digital manufacturing in agro-industrial contexts.

3.3 Constructing Intelligent Knowledge Graphs to Enhance Digital Intelligence

To align with national efforts in online and smart education, the course integrates artificial intelligence technologies to systematically enhance digital and intelligent capabilities in physical chemistry instruction.

At the knowledge framework level, AI tools are used to construct comprehensive knowledge, competency, and value graphs based on curriculum content and professional standards. These graphs logically connect core concepts across thermodynamics, kinetics, and electrochemistry, forming a structured learning map. Resources such as textbooks, lecture slides, instructional designs, case studies, training programs, videos, webpages, and question banks are embedded into the graph to offer students intuitive learning pathways. With AI, these graphs support the training of intelligent teaching models tailored to this course. The system can also generate region-specific learning cases and digital resources—for instance, simulating entropy change in sugarcane evaporation or battery ageing under humid logistics conditions—ensuring that the course content reflects both academic frontiers and industrial needs. Additionally, AI platforms assist instructors in refining teaching designs and presentation materials to improve instructional efficiency.

In terms of teaching process, AI-based platforms provide full-cycle support for smart pedagogy. Before class, teachers can intelligently link knowledge points with case studies and quizzes to assign targeted preview tasks, and then adjust lesson plans based on feedback. During class, interactive tools such as smart sign-in, polling, brainstorming, and instant quizzes enhance engagement and allow real-time monitoring of student learning. After class, the system analyses students' homework, participation, and test results to generate personalized learning paths and resource recommendations that meet diverse learning needs. AI teaching assistants offer additional support for students while providing instructors with teaching analytics. The "AI Time Machine" function, for example, visualizes activity summaries and knowledge coverage, monitors learning progress, and generates feedback to help teachers identify learning bottlenecks and refine teaching strategies.

Regarding assessment, AI integration enables the development of a multi-dimensional evaluation system that goes beyond theoretical testing. It tracks student performance in experimental operations, data analysis, and problem-solving. Automated scoring combined with personalized feedback ensures fairness and depth in evaluation, helping students identify weaknesses and formulate targeted improvements.

By embedding AI into teaching methods, the course effectively breaks from traditional teacher-centered models and establishes a smart, closed-loop instructional system. This comprehensive tracking and feedback mechanism not only improves student learning outcomes but also provides data-driven insights for ongoing curriculum reform and teaching optimization—paving the way for more personalized and intelligent education.

3.4 Strengthening School–Enterprise Collaboration to Empower Engineering Practice

To address the imbalance between theoretical teaching and limited practical training in physical chemistry, the curriculum integrates AI-driven virtual simulation and online practice platforms to reinforce application-oriented and outcome-based education.

By leveraging virtual laboratories and intelligent simulation platforms, students can engage with complex experiments and industrial scenarios even when physical access is restricted. For instance, in traditional experiments involving phase equilibria and reaction kinetics, limitations such as expensive instrumentation or safety concerns often hinder student participation. The virtual platforms simulate realistic laboratory environments where students can repeatedly adjust parameters—such as supersaturation or temperature gradients in crystallization—and observe their impact on experimental outcomes. These tools not only deepen students' understanding of theoretical principles but also develop hands-on skills and engineering experience. AI algorithms further enhance this process by analyzing real-time data and predicting outcomes, enabling dynamic optimization of virtual experiments. When simulating chemical processes, the system offers personalized suggestions based on students' prior operations and experimental data, guiding them in understanding how changes in process variables affect product performance. Moreover, the platform adapts experimental difficulty and content according to individual learning progress and feedback, achieving intelligent, personalized guidance.

In parallel, the course emphasizes industry–education collaboration to reinforce engineering practice. Collaborative arrangements with local enterprise enable students to analyze real-world system-efficiency data, optimize electrolyte parameters under high humidity, and tune parameters such as alkali concentration in alumina production. Through AI-driven resource matching, students engage with enterprise projects—for example, modelling electrolyte stability under heat using impedance-spectroscopy data, or predicting voltage-control strategies in anodization plants. This in-depth collaboration substantially elevates students' ability to translate theoretical knowledge into tangible engineering solutions, enhancing the course's industrial relevance.

4. Conclusion

This paper explores the reform of the Physical Chemistry course at Guilin University of Technology in China under the background of artificial intelligence, aiming to improve its local relevance, interdisciplinary integration, digital intelligence, and engineering orientation. First, course content is aligned with Guangxi's regional industries, such as new energy vehicles and non-ferrous metallurgy, to enhance contextual applicability. Second, interdisciplinary integration is strengthened by embedding intelligent technologies like machine learning to support smart manufacturing. Third, intelligent knowledge graphs are constructed to reorganize course knowledge and promote digital and intelligent teaching. Finally, a school–enterprise collaborative mechanism is established to facilitate the transformation of theoretical knowledge into practical engineering capabilities. These reforms collectively support the cultivation of high-quality engineering talents and the upgrading of regional industries.

References

[1] Seifedine Kadry. Artificial Intelligence and Education. IntechOpen: Rijeka, 2024,707: 1-286.
[2] Jay Lee, Hossein Davari, Jaskaran Singh, et al. Industrial Artificial Intelligence for industry 4.0-based manufacturing systems. Manufacturing Letters, 2018, 18: 20-23.
[3] Chenting Yi. The Significance and Practical Paths of Artificial Intelligence Empowerment of Talent Training of Colleges and Universities. Heilongjiang Education (Research and Evaluation of Higher Education), 2024, (12): 49-52.
[4] Yanyan Li, Fei Ye, Jianbo Zhang, et al. Teaching Reform on Physical Chemistry Experiment of Material Major Based on the "New Engineering" and "Double First-Class" Development. Guangzhou Chemical Industry, 2021, 49(23): 166-167.
[5] Denghua Zhong. Connotations and Actions for Establishing the Emerging Engineering Education. Research in Higher Education of Engineering, 2017, (03): 1-6.
[6] Caifang Cao, Gengfeng Deng, Yunfen Jiao, et al. Innovation and Practice in Physical Chemistry Course Instruction. Journal of Higher Education, 2024, 10(28): 75-78.
[7] Shuyan Li, Kunpeng Zhang, Yuling Liu. Exploration and Practice of Teaching Reform of Physical Chemistry Course Based on OBE Concept. Farm Machinery Using & Maintenance, 2024, (10): 90-94.
[8] Xijun Wang, Shuang Jiang, Wei Hu, et al. Quantitatively Determining Surface–Adsorbate Properties from Vibrational Spectroscopy with Interpretable Machine Learning. Journal of the American Chemical Society, 2022, 144: 16069-16076.