

AI-Enabled Reform and Practice of Analytical Chemistry Teaching for Health Inspection and Quarantine Majors

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Abstract: As a fundamental course for Health Inspection and Quarantine majors, analytical chemistry entails both rigorous theoretical frameworks and intensive practical operations. However, students admitted via the spring college entrance examination often exhibit insufficient chemistry prerequisites, conceptual cognitive bottlenecks, and procedural noncompliance in laboratories, while conventional one-size-fits-all pedagogy fails to address diversified learning trajectories. Grounded in Outcome-Based Education (OBE) principles, this study systematically integrates artificial intelligence (AI) into the instructional ecosystem through four synergistic pathways: AI-enhanced visual analytics for theory abstraction, virtual simulation platforms for pre-laboratory rehearsal, adaptive tiered tutoring for individualized support, and intelligent whole-process performance tracking. Empirical findings indicate that this AI-driven model effectively mitigates entry barriers, alleviates resource constraints in experimental training, counteracts student disengagement, and substantially elevates both instructional efficacy and hands-on professional competence. This reform provides a transferable paradigm for nurturing application-oriented public health talents aligned with contemporary inspection and quarantine workforce requirements.

Keywords: Artificial intelligence; Health inspection and quarantine; Analytical chemistry; OBE philosophy; Pedagogical reform

Online publication: June 26, 2026

1. Introduction

Analytical Chemistry constitutes a cornerstone foundational course for the Health Inspection and Quarantine major in medical colleges and universities, characterized by its rigorous theoretical underpinnings, strong logical coherence, and pronounced practical orientation^[1]. It serves as an indispensable prerequisite for subsequent professional training in physicochemical and microbiological quantitative testing of water, air, food, and public-use commodities. The syllabus encompasses core domains including chemical quantitative

analysis, spectroscopic and chromatographic detection principles, error theory and data processing, and instrumental analytical techniques. However, the abstract nature of formula derivations, the opacity of instrumental mechanisms, and the complexity of quantitative calculations impose a considerable cognitive threshold on students, particularly those with limited pre-existing chemistry proficiency.

At present, the student body of this major is structurally diverse, with a notable proportion coming from the spring college entrance examination cohort. These students commonly exhibit weak high-school chemistry foundations, insufficient quantitative calculation abilities, and underdeveloped scientific reasoning. In traditional classrooms, they are highly prone to incomprehension, falling behind, and diminished learning motivation, resulting in pronounced anxiety toward theoretical study, mechanical imitation in experimental operations, non-standard data processing, and weak awareness of workplace application. The conventional teaching model of “theoretical indoctrination plus uniform experiments” is no longer compatible with current learning conditions and professional training objectives.

The accelerating integration of artificial intelligence (AI) technologies into higher education has introduced transformative pedagogical affordances, including intelligent interactive Q&A systems, multimodal visualization tools, virtual simulation platforms, learning analytics-driven student profiling, and automated assessment mechanisms ^[2]. These developments present unprecedented opportunities for curriculum reform in discipline-specific contexts. Leveraging AI to augment the entire instructional continuum—from theoretical conceptualization to experimental skill acquisition—in the Analytical Chemistry course for the Health Inspection and Quarantine major can systematically address enduring pedagogical challenges: the steep learning curve for underprepared learners, suboptimal classroom engagement, constraints in experimental resource allocation, and the perennial absence of individualized instruction. This technological integration, when guided by Outcome-Based Education (OBE) principles ^[3], facilitates the construction of a novel pedagogical framework that is genuinely student-centered and explicitly oriented toward workplace-defined competency outcomes, thereby bridging the gap between academic instruction and professional practice in public health testing.

2. AI-empowered theoretical classroom instruction

In theoretical classroom teaching, AI technologies can effectively address the persistent pedagogical challenges inherent in Analytical Chemistry—namely, the abstractness of knowledge, students’ cognitive difficulties, and waning learning motivation ^[2]. Conventional Analytical Chemistry instruction has predominantly emphasized formula derivation, theoretical exposition, and systematic knowledge structuring, often detached from the authentic professional contexts of health inspection and quarantine positions. Consequently, students with weak foundational knowledge struggle to construct coherent cognitive frameworks, rendering them highly susceptible to learning burnout.

Leveraging the multimodal content generation capabilities of generative AI, instructors can design authentic work-based case scenarios grounded in the actual professional practice of health inspection and quarantine, encompassing real-world testing contexts such as disease control diagnostics, public health surveillance, food safety screening, and environmental pollutant monitoring. Abstract theoretical constructs—including the Lambert-Beer law, titration principles, chromatographic separation mechanisms, error propagation, and significant figure processing—can be embedded within concrete detection tasks, such as

heavy metal analysis in water quality, quantitative determination of food additives, and VOCs monitoring in ambient air. This pedagogical strategy shifts the instructional paradigm from purely theoretical and formula-centric delivery toward application-oriented contextual learning, enabling students to clearly perceive the practical utility of course knowledge in their future professional roles and effectively dismantling the counterproductive misconception that “what is learned is of no practical use.”

Furthermore, AI technologies can generate dynamic schematic diagrams, principle-deconstructing animations, and tiered explanatory content targeting key instructional bottlenecks—including acid-base equilibrium, spectrophotometric principles, and instrumental analysis mechanisms. These visual and interactive representations render microscopic, abstract chemical processes and instrumental operations tangible and intuitively comprehensible, thereby substantially lowering the cognitive entry barrier for underprepared learners.

At the level of interactive classroom engagement, AI can be integrated with the BOPPPS instructional model and OBE requirements to establish a closed-loop teaching framework encompassing pre-class diagnostic assessment, in-class precision instruction, and post-class targeted reinforcement. Prior to formal instruction, AI-powered intelligent question banks conduct foundational knowledge surveys to precisely identify class-wide common weaknesses. During classroom sessions, AI generates tiered practice problems, discussion prompts, and case analysis tasks, fostering an interactive learning environment that fundamentally departs from traditional one-way lecture-based delivery. Additionally, a course-specific AI teaching assistant, built upon retrieval-augmented generation (RAG) technology, can integrate curated institutional resources—including textbooks, presentation slides, national industry standards, and workplace case studies—to provide students with round-the-clock Q&A support. This addresses the persistent issue of unresolved questions and knowledge accumulation gaps that often arise after class, significantly reducing the probability of underperforming students falling behind their peers.

3. AI-enabled experimental instruction

In the experimental instruction of analytical chemistry, AI technology can construct a virtual-reality-integrated laboratory teaching system encompassing “virtual preview, physical practice, intelligent error correction, and data empowerment,” effectively compensating for the shortcomings of traditional experimental teaching. Practical experiments in analytical chemistry for the Health Inspection and Quarantine major cover titration analysis, sample pretreatment, spectrophotometric detection, and chromatographic and spectroscopic instrumental analysis. These are constrained by practical realities such as limited availability of large-scale instruments, high equipment precision and cost, expensive consumables, significant risks associated with erroneous operations, and steep learning curves for students. Underprepared students commonly exhibit insufficient preparation, non-standard operations, chaotic data processing, and inability to analyze anomalies^[4].

Through AI-driven virtual simulation platforms, students can complete full-process simulated operations before physical labs, familiarizing themselves in advance with core procedures such as standard solution preparation, sample digestion, titration operations, instrument parameter setting, and injection detection. They can visually observe experimental deviations and safety risks resulting from erroneous operations. Repeated simulation training solidifies operational foundations and effectively lowers the threshold for

physical laboratory work, achieving the pedagogical effect of flipped laboratory classrooms.

During physical experiments, AI visual recognition and intelligent diagnostic technologies monitor the standardization of student operations in real time, providing immediate error correction guidance for critical steps such as titration speed, pipetting and volumetric procedures, reagent addition, and instrument calibration. Simultaneously, the system intelligently identifies experimental anomalies, including chromatographic impurity peaks, baseline drift, abnormal absorbance, and recovery rate deviations. Combined with the matrix characteristics of public health samples, it assists students in analyzing error sources and experimental problems, cultivating core professional competencies in test result evaluation and quality control.

In the data processing and instructional summary phase, AI technology assists students with repetitive tasks such as standard curve plotting, concentration conversion, recovery rate calculation, and error analysis, preventing manual calculation errors while guiding students to conduct data analysis in accordance with national health inspection standards. This approach alleviates the burden of mechanical computation while preserving training in independent thinking and result analysis, avoiding competency deficits caused by excessive automation. Instructors can also leverage AI in conjunction with industry standards to independently design comprehensive, innovative experiments involving food, water quality, and environmental pollutants, aligning with the operational demands of disease control centers and third-party testing agencies, thereby enhancing the professional relevance and workplace adaptability of experimental instruction.

4. AI-enabled tiered personalized instruction

AI technology can achieve tiered personalized instruction by leveraging large-scale learning analytics data, effectively addressing the inherent drawbacks of the “one-size-fits-all” approach arising from the marked heterogeneity in students’ chemistry foundations within this major ^[5-7]. Students in the Health Inspection and Quarantine program exhibit significant disparities in chemistry background; traditional uniform teaching models struggle to simultaneously support underprepared students in catching up and challenge high-achieving students with advanced content, readily producing polarized learning outcomes. Artificial intelligence can construct individual learning profiles by collecting multidimensional data encompassing pre-class preparation, classroom responses, homework completion, experimental operations, and accumulated errors. This enables precise differentiation of knowledge gaps and competency levels among students.

For underprepared students from the spring college entrance examination cohort, AI delivers targeted remedial resources in foundational chemistry, simplified principle explanations, and scaffolded basic exercises. Complex formula derivations are de-emphasized while practical application and foundational calculation training are strengthened, gradually helping students close their knowledge gaps. For intermediate-level students, instruction focuses on core course difficulties, delivering case-based exercises and experimental tasks aligned with professional positions to solidify core knowledge and practical competence. For high-achieving students with surplus capacity, AI intelligently pushes expanded literature and research content on AI-assisted detection, modern instrumental analysis, and cutting-edge public health testing technologies, broadening professional horizons and cultivating research innovation capabilities.

This AI-based tiered instructional model breaks the limitations of uniform classroom delivery in

traditional settings, truly realizing individualized teaching according to aptitude. It effectively narrows class-wide learning gaps and comprehensively improves the quality of analytical chemistry learning for all students in the major.

5. AI-enabled whole-process teaching assessment

AI technology empowers diversified whole-process teaching assessment, effectively completing the OBE instructional closed loop and achieving integrated development of teaching, learning, and assessment. Traditional analytical chemistry assessment relies predominantly on final examination scores, suffering from single-dimensional evaluation, absence of process-oriented assessment, and insufficient competency evaluation. Consequently, it fails to comprehensively reflect students' practical abilities, application competencies, and professional literacy. Artificial intelligence can record whole-process learning analytics data, including preparation status, classroom interaction performance, virtual simulation operations, experimental data, homework errors, and post-class Q&A feedback. It automatically generates class-wide and individual learning analytics reports, enabling instructors to precisely grasp teaching effectiveness and dynamically adjust instructional priorities, difficult points, and pacing.

In assessment design, AI can generate tiered questions—basic, applied, and expanded—based on teaching objectives, enriching assessment formats by adding competency-oriented content such as public health testing case analysis, experimental error evaluation, and testing protocol design, thereby transcending the limitations of traditional written examinations. Simultaneously, AI-powered grading systems can efficiently complete batch grading of homework, examinations, and laboratory reports, with particular emphasis on identifying professionally typical issues such as significant figure errors, calculation logic errors, and non-standard error analysis. The system accurately annotates error causes and provides improvement suggestions, substantially reducing instructors' mechanical grading workload. This allows instructors to devote more energy to instructional design, thinking guidance, and personalized tutoring, effectively enhancing the precision, comprehensiveness, and timeliness of teaching assessment while continuously optimizing course quality.

6. Risk prevention and standardized application

In the process of carrying out teaching reform relying on AI technology, there still exist shortcomings in technology application and potential teaching risks, necessitating the establishment of standardized application frameworks and coping strategies. First, artificial intelligence has inherent “hallucination” issues; errors may occur in formula derivation, citation of national standards, experimental parameters, and data calculation. If students directly copy AI-generated results, this violates the core professional quality of rigorous truth-seeking in the inspection discipline.

In response, course-specific knowledge repositories should be constructed during instruction, restricting data sources to formal sources such as textbooks, national industry standards, and authoritative teaching and research literature. Students must be required to manually verify and validate AI-generated outputs, cultivating rigorous professional thinking and traceability awareness. Second, some students exhibit over-dependence on AI, directly using it to complete exercise calculations and laboratory report writing, thereby losing independent thinking and autonomous learning capabilities.

Instruction must clearly define the boundaries of AI tool usage, positioning AI as a tool for learning assistance, Q&A error correction, and data processing. Direct copying of AI answers must be strictly prohibited, with reinforced training in students' abilities to independently calculate, analyze, and summarize. Meanwhile, artificial intelligence can only serve as a teaching auxiliary and cannot replace instructors' classroom guidance, thinking inspiration, or hands-on training in physical experiments. Core instructional segments such as titration operations, large-scale instrument operation, experimental collaboration, and teacher-student interaction must remain primarily offline, preventing technology stacking and inversion of priorities.

Furthermore, some instructors exhibit insufficient competence in applying AI to teaching, manifesting as an inability to use the technology, poor application, or its misuse. Institutions should institutionalize AI teaching skills training, guiding instructors to scientifically design the integration of AI into instructional processes in accordance with the specific learning conditions of the major and course characteristics, thereby enhancing the standardization and effectiveness of intelligent teaching.

7. Conclusion

In conclusion, integrating AI technology into the theoretical and experimental teaching of Analytical Chemistry for the Health Inspection and Quarantine major can precisely accommodate the professional characteristics of weak chemistry foundations, significant learning disparities, and strong workplace practicality among students. Through diversified approaches including visualized instruction, virtual-reality integrated experiments, tiered personalized tutoring, and whole-process intelligent assessment, this model effectively lowers course learning thresholds, stimulates student initiative, and addresses prominent issues in traditional teaching such as theoretical obscurity, insufficient practical training, single-dimensional assessment, and difficulty in individualized instruction. AI-empowered teaching not only solidifies students' theoretical foundations and practical skills in analytical chemistry but also aligns with the workplace demands of disease control centers, environmental testing, and food safety monitoring. It cultivates rigorous testing thinking, data processing capabilities, and quality control awareness, conforming to the OBE outcome-oriented training objectives for medical inspection professionals, and provides a novel pathway for teaching reform in cultivating high-quality applied talent for health inspection and quarantine in the new era.

Disclosure statement

The authors declare no conflict of interest.

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