Exploring Teaching Reform Strategies for Analytical Chemistry Experiments Oriented towards the Cultivation of High-Quality Applied Talents

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Abstract: Against the backdrop of the construction of application-oriented high-level universities, the reform of analytical chemistry laboratory courses has become a critical component in cultivating high-quality application-oriented talent. This study established a tiered and progressive laboratory course system through measures such as optimising the curriculum structure, innovating teaching content and methods, introducing advanced instrumentation and equipment, reforming assessment and evaluation methods, and strengthening faculty development. The reform aims to enhance students' practical skills, innovative thinking, and research literacy to meet the evolving societal demands for skilled professionals in the new era.

Keywords: Analytical Chemistry Experiments; Curriculum Optimisation; Teaching Reform; Innovative Ability

1. Introduction

Higher education is moving towards high-quality development, and cultivating high-quality, application-oriented professional talent has become a crucial pillar of the national strategy to promote innovation-driven development. This presents new challenges for university curriculum reform[1]. As a core practical course in fields such as chemistry, chemical engineering, environmental science, and food science, analytical chemistry experiments are not only a crucial component in enhancing students' practical skills and innovative thinking but also a fundamental foundation for modern technological and industrial development [3-4]. However, traditional experimental teaching methods often suffer from issues such as slow content updates, limited methodological diversity, and failure to keep pace with industry demands [5-6], making them inadequate to meet the current societal requirements for the capabilities of applied professionals.

Currently, with the rapid advancement of analytical technologies and the increasing demands of the industry, analytical chemistry laboratory courses urgently need to transition to a student-centred approach with the goal of enhancing students' capabilities. Strategies such as optimising course structures, updating textbook content, and innovating teaching methods can be employed to enhance the sophistication, innovation, and challenge of the courses [7-11]. Additionally, integrating course-based ideological and political education into teaching has opened new avenues for cultivating students' scientific spirit and sense of social responsibility[2][12]. Against this backdrop, this study aims to cultivate high-quality applied talents by exploring reform directions and practical strategies for analytical chemistry laboratory teaching, and establishing a tiered, progressive, and industry-academia integrated experimental course system. While solidifying students' professional foundations, the emphasis is placed on the horizontal and vertical connections within the knowledge system and its application and transformation, aiming to cultivate students' scientific thinking, professional competence, and sense of social responsibility, thereby achieving the teaching objective of 'integrating learning and thinking, knowledge and action', and providing a reference for cultivating composite talents with solid professional skills and innovative capabilities.

2. Analysis of the Current Status and Issues of the Analytical Chemistry Laboratory Course System

In the teaching of chemistry and related disciplines at universities, analytical chemistry laboratory courses serve as a core component for enhancing students' practical skills, fostering innovative thinking, and cultivating scientific literacy. However, the current course systems at most universities exhibit several significant issues. First, teaching materials are outdated and lag behind current standards, with experiments primarily focused on verification-based content. There is a lack of comprehensive, design-oriented, and innovative approaches, resulting in a disconnect from the actual needs of research and industry. This leads to insufficient practical application capabilities among students, failing to meet the requirements for cultivating applied talent. Second, teaching methods are rigid, with highly standardised experimental procedures, leaving students with limited space for independent thinking and exploration, thereby restricting the development of their innovative abilities. Additionally, the application of information-based teaching tools is insufficient, with virtual simulation and online data processing tools not fully utilised, resulting in low course efficiency. Third, experimental equipment is updated slowly, with some universities possessing outdated instruments and lacking modern automated and intelligent analytical equipment. Furthermore, the number of large-scale instruments is limited, resulting in insufficient practical operation opportunities for students, thereby hindering the improvement of their experimental skills. Fourth, the evaluation system is too simple, with too much emphasis on lab report scores, and not enough focus on assessing things like how well students follow procedures, their data analysis skills, problem-solving skills, innovative thinking, and teamwork abilities. There's no proper evaluation framework yet. Fifth, the teaching staff lacks real-world experience, with some teachers out of touch with the latest research and industry needs, making it hard for them to keep up with cutting-edge technology and industry demands. Equipment technicians also don't get enough training, which affects the maintenance and efficient use of large instruments, significantly limiting improvements in teaching quality.

3. Strategies for Optimising the Analytical Chemistry Laboratory Course System and Reforming Teaching Content

3.1 Optimise the Course System and Adopt a Tiered, Progressive Design

Foundational-level experiments serve as the cornerstone of students' professional knowledge, with systematic training aimed at strengthening practical skills and core competencies. The implementation of this includes four key components. First, standardise basic operational procedures through foundational experiments such as precise measurements, solution preparation, equipment calibration, and titration analysis to help students master critical operational skills. For example, in titration experiments, strict adherence to operational steps is required to ensure precise endpoint determination, reinforcing the concept of ‘quantity’. Second, enhancing instrument usage capabilities involves systematically teaching the operational principles, usage standards, and daily maintenance knowledge of common instruments such as spectrophotometers, pH meters, and potentiometric analysers to improve professional operational proficiency. Third, it cultivates scientific experimental abilities, focusing on training core skills such as error analysis, data management, and experimental record-keeping. Students are required to master effective numerical calculations and error propagation calculations, and to record data in a standardised manner to develop rigorous habits. Fourth, it shapes a scientific attitude through laboratory safety guidance and the cultivation of operational habits, establishing an honest, rigorous, and excellence-seeking scientific research attitude, such as strictly prohibiting the tampering of experimental data and strengthening scientific research integrity awareness.

Comprehensive-level experiments break through disciplinary boundaries through the integration of multiple technologies, with a focus on enhancing students' interdisciplinary application and comprehensive practical abilities. The core lies in integrating multiple technical methods to allow students to experience the entire analysis process, thereby strengthening their information acquisition and processing abilities. For example, the ‘Water Quality COD Determination and Spectrophotometry with Data Processing’ experiment covers the entire process from sample collection, pre-treatment, instrument testing to data analysis. Projects with real-world contexts can also be designed, such as ‘Systematic Analysis of Food Preservative Content’ encouraging students to independently design analytical methods and combine multiple testing techniques to solve practical problems. Complex experiments are conducted in group settings, with clear division of labour among members, collaborative completion of experiment reports, and presentation of results, effectively cultivating students' teamwork and communication skills while reinforcing the integration of theory and practice.

Innovative-level experiments are key to cultivating students' innovative thinking and research capabilities, significantly enhancing overall research and innovation standards. Implementation pathways include three aspects: first, introducing faculty research projects, transforming cutting-edge studies such as nanomaterial property analysis and biological sample testing into teaching experiments, enabling students to participate in actual research to grasp field dynamics; second, establishing an innovative experiment resource repository and offering open-format classrooms to support students in independently selecting topics or submitting proposals, such as conducting ‘Innovative Electrochemical Sensor Design and Application’ research; third, promoting interdisciplinary innovation by encouraging the design of experiments based on professional specialties, such as medical testing majors studying antibiotic residues in water and environmental majors exploring the application of pollutant adsorption materials.

Modular design and virtual simulation are important components of the tiered and progressive curriculum system. The curriculum covers application-oriented modules such as food safety testing, environmental pollution analysis, and drug analysis, allowing students to choose based on their interests, significantly enhancing the relevance of teaching. In teaching, a blended learning model is adopted, where students first learn the principles and operation of large instruments such as HPLC and AAS through virtual simulation software, ensuring equipment safety while improving teaching efficiency; followed by practical experiments to deepen students' understanding and application skills. Additionally, a ‘Modern Analytical Technology Experience’ module has been introduced, incorporating advanced equipment like Raman spectroscopy and mass spectrometry to broaden students' professional horizons. This design ensures a stepwise enhancement of students' capabilities from foundational to comprehensive and innovative levels, laying a solid foundation for cultivating high-level applied talents.

3.2 Reform of Teaching Content

Curriculum reform focuses on practicality and cutting-edge content, first eliminating outdated experiments such as basic confirmation tests, and introducing new application-oriented case studies such as food additive detection, soil heavy metal identification, and drug active ingredient quantification to enhance practicality. In terms of hardware, modern analytical tools such as inductively coupled plasma mass spectrometry (ICP-MS), electrochemical sensors, and microfluidic chips have been introduced; interdisciplinary integration of environmental science and biomedical knowledge has been implemented to design experiments such as wastewater treatment plant water quality assessment, PCR product quantitative analysis, and drug metabolism kinetics simulation. Digital literacy development is strengthened through the use of tools like Origin and Python to process experimental results, fostering big data analysis thinking. Concurrently, digital resources such as educational videos and experimental simulation platforms are being developed. Textbooks emphasize safety education, include modern instrument operation guidelines, and incorporate digital technology-based materials tailored to the programme’s specialisation to help students grasp the principles and operational methods of complex equipment.

3.3 Innovate Teaching Methods and Approaches

Innovative teaching integrates diverse modes such as previewing, explanation, discussion, ideological and political case studies, online lectures, and competitions. The flipped classroom model is adopted, with pre-class preview questions and in-class focus on discussion and practice. Ideological and political case studies are incorporated into the curriculum to cultivate social responsibility and ethics. Practical projects such as pharmaceutical quality assessment and industrial quality control are launched in collaboration with enterprises to enhance teaching effectiveness and application alignment.

3.3.1 Systematic development of diversified teaching models

The construction of a blended learning model can enhance learning outcomes, efficiency, and engagement while accommodating personalized learning needs. Pre-class micro-lecture videos explain experimental principles and procedures, and online quizzes are designed for pre-class preparation. Questions are collected through real-time chat in the Rain Classroom platform. In-class instruction employs a 'three-phase' teaching method: 20% of time for key concept explanation, 50% for group practical exercises, and 30% for summary and enhancement; Simultaneously implement a rotating lab bench system and a 'technical challenge breakthrough' workstation. After class, use an intelligent grading system to detect abnormal data, establish online discussion forums by project, and host a 'Best Experimental Design' competition. Deeply apply the PBL teaching method, using 'Industrial Park Water Pollution Analysis' as an example, to cultivate comprehensive research thinking through five stages: background provision, plan formulation, indicator testing, data analysis, and report writing.

3.3.2 Refined implementation of the flipped classroom

Develop pre-class resource packages using equipment disassembly videos, dynamic diagrams, and 3D accident reconstruction to assist learning and safety assessment. Design classroom 'question auctions' to enhance problem analysis and solving skills through questioning and answering; conduct 'error correction competitions' to assess basic operational skills using videos of incorrect operations; set up 'data analysis stations' to diagnose the sources of abnormal data and strengthen data processing skills. Link pre-class preparation completion to classroom performance for grading, establish 'flipped teaching assistants' to support instruction, and introduce an artificial intelligence system to assess pre-class preparation effectiveness, enhancing assessment accuracy and efficiency.

3.3.3 Organic integration of course ideological and political education

Course ideological and political education integration cultivates a sense of social responsibility and professional ethics through contextualised design. Set up environmental protection-related experimental cases, simulate enterprise production scenarios, and have student teams evaluate processes, design pollution reduction and energy-saving plans, and balance economic benefits with social responsibility; incorporate role-playing to present plans, invite experts for feedback, and deepen understanding of responsibility.

Combine professional experiments with ideological and political themes: melamine detection linked to food safety ethics, heavy metal analysis combined with environmental public interest litigation, and pharmaceutical testing connected to warnings about drug-related incidents. Experimental guidance incorporates 'scientist story' micro-videos to cultivate a scientific spirit, and 'industry standard analysis' is implemented in industry sample testing to strengthen industry understanding. Through scenario simulation, a 'professional ethics stage' is constructed, and the effectiveness of ideological and political integration is monitored through a system of assessment questionnaires, reflection journals, and value tracking.

3.3.4 Practical innovation through school-enterprise collaboration

School-enterprise collaboration focuses on practical training, with tablet weight variation testing and sterile testing of injections conducted in accordance with GMP standards in the pharmaceutical field; industrial quality control develops technologies such as lubricant viscosity testing and steel spectral analysis. A 'dual mentor' system is implemented, with job task lists and enterprise case conversion processes established. A quality monitoring system is established, with clear enterprise evaluation criteria, regular analysis of training effectiveness, and the creation of graduate capability tracking archives to ensure the effectiveness of practical training.

3.3.5 Deep integration of information-based teaching methods

Virtual simulation systems are used for high-risk experiments (such as hydrofluoric acid simulations), disassembly of expensive equipment, and simulation of complex microscopic processes. A mobile learning platform has been developed to enable live experiment streaming, QR code operation prompts, and AR guidance, while constructing an intelligent warning system for abnormal operations. Data analysis tools are used to develop processing templates, standard curve databases, and data reliability assessment modules to enhance teaching efficiency.

3.3.6 Enhance the cultivation of innovative capabilities through competitions

Establish a tiered competition system: consolidate foundational skills through experimental skill competitions, enhance proficiency through analytical method design competitions, and achieve innovation through the commercialisation of research outcomes. Create distinctive competitions such as the ‘24-Hour Experimental Marathon’ ‘Cost-Effectiveness Comparison of Testing Protocols’ and ‘Laboratory Safety Expert’ which respectively assess comprehensive skills, cost management, and emergency response capabilities. Establish a technology transfer mechanism: incorporate outstanding proposals into a project repository, promote innovative achievements to industry competitions, and apply for patent protection for practical outcomes.

These reforms are accompanied by detailed implementation plans and regulatory mechanisms to promote educational diversity, establish a ‘student-centred’ competency development framework, and enhance practical and innovative qualities.

3.4 Establish Safeguards and Evaluation Systems

Safeguards and evaluation systems are constructed in three areas: in terms of hardware, seek support from the university and colleges to update outdated equipment and establish a shared platform to avoid duplicate purchases; open up decommissioned instruments for observation experiments, allowing students to disassemble and observe them independently to improve utilisation rates and stimulate innovative thinking; and simultaneously build safe and environmentally friendly laboratories equipped with waste liquid classification and treatment facilities.

In terms of faculty development, encourage teachers to participate in industry practice to strengthen their engineering and technical application capabilities; implement a ‘mentoring’ mechanism to assist new teachers in improving their skills; and promote the integration of research findings into experimental courses to broaden students' horizons and foster scientific research thinking.

The comprehensive assessment system emphasizes flexibility, with process evaluations covering attendance, pre-class reports, and experimental reports, and new dimensions such as experimental attitude, question-and-answer performance, data analysis, and discussion. The ‘lesson presentation’ component is introduced to assess mastery of principles, combined with evaluations of operational standard compliance and team collaboration skills. Simultaneously, evaluation standards for experimental reports and innovation projects are enhanced, and feedback from graduate employment outcomes and corporate satisfaction data are continuously collected to ensure the curriculum aligns with the needs of applied talent cultivation, thereby strengthening students' practical skills and innovative spirit.

4. Conclusions

Against the backdrop of applied university development, this study explored teaching improvements for analytical chemistry laboratory courses. By identifying shortcomings in the curriculum, several optimisation measures were proposed. These reforms not only provide strong support for cultivating high-quality applied talents suited to the needs of the new era but also offer new insights for the continuous improvement of this course. Moving forward, efforts can be focused on three key directions: strengthening collaboration with enterprises, optimising the application of modern teaching technologies, and refining assessment methods. These initiatives aim to ensure that course content aligns more closely with practical needs while maintaining its cutting-edge and innovative nature.

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References

[1] Juan Hou, Jing Sun, Chen Zhou, Yining Wang. Exploration of Analytical Chemistry Experiment Teaching Reform Oriented towards Cultivating Top-Notch Innovative Talents. Journal of Higher Education, 2020,11(09):64-67.

[2] Yunqing Duan, Zhiqing Duan, Xin Wu,

Xiaodi Guo. Route for Integrating Ideological and Political Education in Analytical Chemistry Teaching. University Chemistry, 2022,37(07):82-88.

[3] Huifang Yang, Yanying Wang, Jingjing Hu, Hao Zhou, Zhigao Xu. Exploration on the Reform of Experimental Teaching Mode of Analytical Chemistry. University Education, 2024,(16):52-55+94.

[4] Jinghui Zhang, Wei Shen, Sheng Tang, Ru Jia, Wei Zhong. Exploration and Reflection on Interdisciplinary Teaching of Analytical Chemistry under the New Pattern of International Competition. University Chemistry, 2020,40(07):1-9.

[5] Hai Wu, Tiantian Huang, Qiao Zeng, Huazi Wang, Xiaoyan Jin, Jie Liu, Suhua Fan. Reform and Practice of Diversified Teaching Mode for Analytical Chemistry Experiment. College Chemistry, 2021,36(09): 65-70.

[6] Wenyuan Hu, Jichuan Huo, Guoqing Zhong, Binyao Liu, Qiying Jiang, Qiulin Deng, Dingming Yang, Tinghong Zhang, Hongbo Li, Pingping Zhu. Construction and Exploration of an Innovative Talent Training Practical Curriculum System for Applied Chemistry at Local Universities. College Chemistry, 2020,40(07):55-61.

[7] Qin Li, Pingping Yang, Lijun Guo, Haiyue Li, Huaidong Zhang. Teaching Reform of Biochemistry Experiments for Cultivating Excellent and Outstanding Talents. Research and Exploration in Laboratory, 2024,43(12):127-130,160.

[8] Hongxia Li, Letong Wang, Yongdong Liu, Deyi Zhang, Kunjie Wang. Explorationon the Teaching Reform of Analytical Chemistry Experiment Course Based on the Engineering Certification. The Theory and Practice of Innovation and Entrepreneurship, 2021,4(24):29-31.

[9] Hanhan Fan, Rong Zhang, Jiujuan Zhu. Application of Virtual Simulation Technology in the Experimental Teaching of Analytical Chemistry. Chinese Journal of Chemical Education, 2022,43(20):117-122.

[10] Shudi Zhang, Fangfang Chen, Haiyue Pang, Guihong Wang. Test Report-Oriented Tentative Reform of Analytical Chemistry Experimental Teaching. Chinese Journal of Chemical Education, 2023,44(02):62-67.

[11] Jiao Li, Gu Jin, Qizhi Yao, Hongyu Liu, Lingling Li. Assisting Experimental Teaching and Management of Postgraduates in Universities. Chinese Journal of Chemical Education, 2021,42 (22):88-92.

[12] Dandan Zhang, Weihan Huang, Xin Huang, Shaobo Wang, Haijuan Du, Keqian Hao, Qing Wang. Innovation and Practice of the Basic Chemistry Experiment Courses with “Integration of Course Ideological and Political Education, Highlighting Characteristics and Emphasizing Process”. Chinese Journal of Applied Chemistry, 2020,42(05):712-722.