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Reform and Practice of Science-Education Integration in Basic Chemistry Experiment Courses

Jing Zhang*, Yufeng Sun, Haiyan Yu, Zhongxue Fang, Yanqing Wang, Bin Guo*
School of Chemical and Environmental Engineering, Yancheng Teachers University
No. 2 Xiwang Street, Yancheng 224007, China
*E-mail: zhangj02@yctu.edu.cn (J. Z.), guob@yctu.edu.cn (B. G.)

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Abstract

Against the strategic backdrop of high-quality development in higher education and the construction of ‘Emerging Engineering Education’ in the new era, deepening the reform of basic chemistry experiment courses is critical to cultivating innovative talents in chemistry. From the perspective of ‘integration of scientific research and education’, current basic chemistry experiment courses are confronted with several prominent challenges, including the disconnection between teaching content and disciplinary frontiers, an excessively high proportion of verification experiments, insufficient training in scientific research thinking resulting from ‘cookbook-style’ teaching, as well as a singular evaluation method and an inadequate support mechanism. To address these challenges, it further puts forward targeted reform strategies, such as restructuring teaching content, innovating teaching methodologies, optimizing the evaluation system, and improving support mechanisms. The objective is to convert scientific research advantages into tangible educational outcomes, thereby enhancing the quality of basic chemistry experiment courses and fostering students’ innovative and practical abilities.

Keywords: Basic Chemistry Experiment, Integration of Scientific Research and Education, Challenge, Reform

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1. Introduction

At present, higher education in China is entering a critical period of connotative development. The national policy of ‘Taking Undergraduate Education as the Foundation’[1-2] and the strategy for constructing ‘Emerging Engineering Education’[3-4] have imposed higher standards for the quality of talent cultivation. The in-depth implementation of the ‘Six Excellence and One Top-notch’ Plan 2.0 explicitly mandates strengthening students’ practical and innovative capabilities[5], which provides a clear guideline for the reform of experimental teaching in fundamental disciplines such as chemistry. As a vital bridge linking theory with practice and a core carrier for fostering students’ scientific thinking and hands-on competencies, the effectiveness of experimental teaching reform directly dictates the quality of innovative talent cultivation. Meanwhile, the discipline of chemistry is integrating with fields such as physics, materials science, biology, and information technology at an unprecedented pace, spawning emerging research directions and cutting-edge characterization technologies. This trend in disciplinary development necessitates that basic chemistry experimental teaching break free from the constraints of the traditional verification-based model, promptly incorporate disciplinary frontiers, and guide students to shift from passive knowledge recipients to active knowledge explorers.

The in-depth implementation of the ‘integration of scientific research and education’[6-8] concept is imperative. Specifically, the organic integration of the latest scientific research findings, methodologies, and practical models into undergraduate teaching—especially in experimental instruction—serves as a fundamental approach to transforming research resources into educational strengths and addressing the long-standing disconnect between teaching and research. Promoting the reform of basic chemistry experiment courses via this integration is not only an inevitable response to national strategic demands but also a crucial lever for aligning with the inherent logic of disciplinary development and enhancing the core competitiveness of talent cultivation. This approach bears significant theoretical and practical significance for nurturing a reserve of chemical professionals who possess solid foundational knowledge, an innovative mindset, and scientific research potential.

2. Teaching Dilemmas in the Basic Chemistry Experiment Courses

2.1 Teaching Contents

At the level of teaching contents, notable rigidity persists in the curriculum system. A considerable number of experimental projects have remained unchanged for years, predominantly comprising classic verification-based experiments that are severely disconnected from current frontier hotspots in chemical research (e.g., new energy materials, precision synthesis, and AI-assisted drug design). Furthermore, the experimental contents are often fragmented and isolated, with modules such as inorganic chemistry, analytical chemistry, organic chemistry, and physical chemistry operating independently. There is a lack of comprehensive projects designed to integrate interdisciplinary knowledge and cultivate students' synthetic abilities, rendering it difficult for them to develop a systematic scientific understanding and research perspective.

2.2 Teaching Process and Methods

At the level of teaching process and methodology, 'cookbook-style' instruction remains predominant. Students strictly follow pre-determined procedures, with the acquisition of expected results as their ultimate objective. This instructional model stifles students' initiative and curiosity, while generally lacking essential training in critical research-oriented thinking—including formulating research questions, designing experimental approaches, analyzing abnormal phenomena, and conducting iterative optimization. Additionally, teaching methods remain relatively simplistic, with inadequate application of modern technologies such as virtual simulation, online data processing, and intelligent experimental equipment. Such underutilization fails to fully tap into the potential of information technology in expanding the boundaries of experimental teaching and improving instructional efficiency.

2.3 Teaching Evaluations and Supporting

At the level of teaching evaluations and supporting mechanisms, assessment methods predominantly focus on the standardization of laboratory reports and the accuracy of experimental results. They are insufficient in effectively evaluating students' innovative thinking, experimental design capabilities, problem-solving skills, and teamwork spirit during the experimental process. Furthermore, due to the pressure of research performance assessment, some teachers lack sufficient motivation to devote themselves to teaching, especially to the time-consuming and labor-intensive reform of experimental instruction. There is also a lack of effective incentive mechanisms to facilitate the integration of scientific research and education. In addition, laboratory management tends to be conservative, with insufficient open time and space allocated for students' independent inquiry, which restricts their opportunities for extended extracurricular exploration and practical investigation.

3. Reform Pathways and Practical Exploration for the Basic Chemistry Experiment Courses

3.1 Establishing a Three-Tiered Experimental Teaching Content System Covering 'Fundamental, Comprehensive, and Innovative' Levels

The experimental teaching contents system should be reconstructed to establish a three-level progressive curriculum structure composed of 'fundamental, comprehensive, and innovative' modules. While focusing on training students' basic operational skills, the fundamental module seamlessly integrates the education of research norms, laboratory safety culture, and data rigor. The comprehensive module designs cross-topic integrated experimental projects, such as 'from ore extraction to the synthesis, characterization, and performance evaluation of metal complexes', to cultivate students' systematic problem-solving capabilities. The core of the innovative module lies in establishing a dynamic mechanism for 'transforming research outcomes into teaching resources'. This mechanism encourages teachers to simplify, adapt, and refine their cutting-edge research topics, converting them into inquiry-based experimental projects suitable for undergraduate students. It also ensures that a considerable proportion of the experimental content is updated annually, thereby guaranteeing the timeliness and pertinence of the curriculum.

3.2 Implementing the 'Project-Led and Digital Empowerment' Teaching Method Reform

The teaching methods should be comprehensively reformed, with the implementation of a new 'project-driven, digitally-empowered' instructional model. Specifically, Project-Based Learning (PBL) is fully adopted in both the comprehensive and innovative modules. This instructional approach engages student teams in addressing real-world problems or research topics, guiding them through the entire process of literature review, experimental design, hands-on experimentation, data analysis, and report writing, thereby simulating authentic scientific research workflows. Virtual simulation experiments are vigorously introduced to replicate high-risk, high-cost, extreme-condition, or micro-scale experimental processes, which significantly expands the dimension of experimental teaching. Additionally, an integrated online-offline hybrid teaching platform is established to effectively support students' personalized and in-depth learning processes.

3.3 Constructing a 'Process-Oriented and Developmental' Multi-Evaluation System

The course evaluation system should be refined through the establishment of a multi-dimensional assessment framework characterized by a 'process-oriented and developmental' approach. Evaluation is integrated throughout the entire learning process, covering the experimental pre-study plan, operational compliance, primary data recording, result analysis and discussion, as well as the final report and defense. This system not only assesses students' knowledge mastery and practical skills but also incorporates evaluation dimensions such as innovativeness, critical thinking, teamwork, and communication capabilities. Additionally, it explores the application of experimental design projects and achievements in disciplinary competitions as important evaluation criteria. Furthermore, the Learning Management System (LMS) is leveraged to document students' learning trajectories, thereby providing them with personalized diagnostic reports on their competency development.

3.4 Improving the Supporting and Guarantee Mechanism for the Integration of Science and Education

Efforts should be made to strengthen the integration of scientific research and education, and to enhance the long-term supporting mechanisms for this integration. Specifically, an integrated teaching and research team consisting of research leaders and pedagogical experts should be established to promote the concept of 'research feeding back into teaching'. Special funds should be appropriated to support the development of small-scale research instruments for teaching purposes and the incubation of new experimental projects. Furthermore, laboratory accessibility should be improved by setting up 'independent inquiry experiment zones' operated under a reservation system. In addition, active efforts should be made to construct collaborative education platforms with enterprises and research institutes, introducing real-world industrial challenges and advanced equipment from research institutions. This initiative will provide students with opportunities to engage in authentic research and engineering environments.

4. Conclusion

From the perspective of the 'integration of scientific research and education', the reform pathways and practical strategies of basic chemistry experiment courses are systematically explored. The core issues to be addressed include insufficient topicality of teaching content, rigidity of pedagogical methods, simplicity of evaluation approaches, and inadequacy of support mechanisms. To tackle these issues, a comprehensive reform framework is proposed. It is centered on 'content restructuring, methodological innovation, evaluation reform, and support enhancement'. Specifically, the framework includes the establishment of a three-tiered teaching content system, the implementation of project-led and digital empowerment teaching methods, the construction of a process-oriented multi-evaluation system, and the improvement of science-education integration supporting mechanisms. The reform translates the macro concept of the 'integration of scientific research and education' into specific design and operational strategies, covering all aspects of basic chemistry experimental teaching. The reform approach effectively stimulates students' learning initiative and research enthusiasm, promoting the synergistic improvement of their knowledge integration, practical innovation, and problem-solving abilities. Moreover, it provides a replicable paradigm for science-education integration in fundamental chemical experimental courses, which plays a pivotal role in promoting talent cultivation quality in chemistry-related fields.

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