

Integration of Hazardous Waste Management and Safety Education into Biotechnology Chemistry Experiments: A Curriculum Reform and Practice

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Abstract: Chemical experiments are crucial in teaching Biotechnology. Improper disposal of hazardous waste from these experiments endangers health and the environment. This paper explores the challenges of managing such waste in Biotechnology courses and through a value-oriented educational approach known as "Curriculum-based Ideological and Political Education," which integrates ethical and social responsibility training into subject teaching. This approach creates a teaching framework with three objectives: knowledge transmission, skill training, and value cultivation. It includes experimental content on hazardous waste management and introduces a four-part teaching model of lectures, case studies, practical training, and virtual simulations. A comprehensive student assessment system is also established. This reform effectively improves students' ability to manage hazardous waste, enhances safety and environmental awareness, and fosters social responsibility, offering a replicable model for the reform chemical experiment courses in Biotechnology-related fields.

Keywords: Biotechnology experimental teaching; Chemical laboratory hazardous waste disposal; Laboratory safety training; Environmental awareness cultivation; Value integration into specialized courses

1. Introduction

Biotechnology is a leading field of the 21st century, requiring strong experimental teaching for talent development. Chemical experimentation is a key course in the Biotechnology curriculum, essential for building students' experimental skills and scientific thinking. However, this process generates large amounts of hazardous waste, including heavy metal solutions, organic solvents, and corrosive substances, which can harm lab personnel and the environment if not properly managed.[1].

In recent years, the Chinese government has increasingly prioritized environmental protection and laboratory safety, prompting the Ministry of Education to issue a series of directives, such as the "Opinions on Strengthening Laboratory Safety Work in Higher Education Institutions" and the "Laboratory Safety Specifications for Higher Education Institutions." These documents explicitly mandate the incorporation of safety education into the talent cultivation framework[2]. Concurrently, there is a widespread consensus within the higher education sector on the necessity of "comprehensively advancing the integration of ideological and political education into university curricula," which requires embedding value formation throughout the entirety of professional course instruction[3]. In this context, the effective integration of hazardous waste management and safety education into the chemical experiment teaching component of the biotechnology curriculum-thereby achieving a cohesive alignment of knowledge dissemination, skill development, and value orientation-has become a critical issue requiring urgent attention in experimental teaching reform.

This study analyzes the challenges of hazardous waste management in a Biotechnology lab course, proposing strategies to integrate waste management, safety, environmental, and ideological education into the curriculum. It suggests creating an assessment system and validates the reform's effectiveness

through teaching practice, aiming to guide similar course reforms.

2. Characteristics of Hazardous Waste in Chemical Experiments for the Biotechnology Major and the Current Status of Safety Education

2.1 Main Types of Hazardous Waste and Their Hazard Characteristics

Chemical experiments in the Biotechnology major generate hazardous waste with diverse and complex compositions, primarily classified as liquid, solid, or gaseous. Liquid waste, the largest category, includes inorganic waste with heavy metals (e.g., chromium, mercury), acid-base waste, organic solvents (e.g., ethanol, acetone), cyanide-containing waste, and waste from cleaning lab equipment. Many of these are highly toxic, corrosive, or carcinogenic, such as hexavalent chromium, mercury, and cyanides, which pose serious health risks[4].

Solid waste predominantly comprises damaged glassware, discarded laboratory consumables (including filter paper, gloves, centrifuge tubes, pipette tips, etc.), expired or ineffective chemical reagents, residual laboratory products, and packaging materials contaminated with hazardous substances[2]. The co-disposal of such solid waste with municipal solid waste has the potential to significantly contaminate soil and groundwater. Gaseous waste primarily arises from the volatilization of volatile reagents (such as concentrated hydrochloric acid, chloroform, and ether) and the production of toxic and hazardous gases during chemical reactions (such as sulfur dioxide, chlorine gas, hydrogen sulfide, and nitrogen oxides), thereby posing a direct threat to the respiratory health of laboratory personnel[5].

2.2 Current Status and Challenges in Safety Education and Hazardous Waste Management

A survey and analysis of chemical experiment instruction for biotechnology majors across several universities have identified significant issues in hazardous waste management and safety education. Primarily, there is a notable disjunction between safety education and experimental instruction. At many institutions, safety education is conducted through standalone lectures or courses, which are not cohesively integrated with the specific content of experimental teaching. Consequently, students acquire safety knowledge without the contextual support of practical experimentation, leading to a often disregard for safety protocols upon entering the laboratory. This disconnect substantially diminishes the efficacy of safety education[3]. Secondly, there is a notable deficiency in the active engagement of students in the hazardous waste management process. Within the framework of traditional experimental pedagogy, the tasks of hazardous waste collection and disposal are predominantly executed by laboratory technicians, relegating students to the passive role of merely transferring waste liquids into pre-designated containers. This "end-of-pipe disposal" methodology effectively denies students the opportunity to comprehensively understand the entire hazardous waste treatment process, thereby hindering the development of their environmental consciousness and the cultivation of standardized operational practices[6]. Thirdly, the incorporation and application of ideological and political dimensions within the curriculum are insufficient. Chemical laboratory instruction inherently possesses a wealth of ideological and political educational resources, such as fostering social responsibility towards environmental protection, upholding ethical standards in scientific research, and developing professional competencies related to safe laboratory practices. However, these elements are frequently neither fully recognized nor effectively integrated into the instructional process[3]. Fourth, the performance evaluation system is incomplete. Current assessment methods primarily focus on experimental reports and operational skills, yet lack systematic evaluation indicators for students' safety awareness, environmental protection behaviors, and compliance with hazardous waste disposal protocols[3].

3. Practical Implementation of Teaching Reform in Hazardous Waste Management and Safety Education

In response to the previously identified challenges, we have conducted a systematic investigation into the reform of teaching methodologies within the chemical experimentation course for Biotechnology majors. This has led to the development of a comprehensive instructional framework encompassing five key dimensions: educational objectives, curricular content, pedagogical models, the integration of ideological and political education, and mechanisms for assessment and evaluation.

3.1 Establishing the "Three-in-One" Teaching Objectives

Drawing upon the tripartite curriculum development philosophy of "knowledge transmission, competency cultivation, and value shaping," we have formulated comprehensive teaching objectives for hazardous waste management and safety education within the chemistry laboratory course[2]. These objectives are structured into three dimensions: A. Knowledge Objectives: Students will gain mastery over the classification standards for hazardous waste in chemical laboratories, including their hazard characteristics and pertinent laws and regulations. They will also learn the fundamental principles and methods for standardized disposal. Additionally, students will understand the limit values for various pollutants as specified in the National Hazardous Waste List and the Integrated Wastewater Discharge Standard[2]. B. Competency Objectives: Students will develop the ability to accurately identify and classify various types of hazardous waste generated during experimental procedures. They will acquire the skills necessary to complete the collection, labeling, temporary storage, and documentation of hazardous waste in accordance with established protocols. Furthermore, students will be able to apply their knowledge to design simple wastewater treatment schemes and will possess basic emergency response capabilities for laboratory accidents[3]. C. Value Objectives: Students will develop a laboratory safety ethos centered on the principle of "Safety First, Prevention Foremost"; they will promote an awareness of ecological civilization that acknowledges "lucid waters and lush mountains as invaluable assets" and instills a profound sense of social responsibility towards environmental protection; and they will nurture a scientific mindset and professional proficiency marked by rigor, meticulousness, and strict adherence to standardized operating procedures [5].

3.2 Restructuring and integrating teaching content for hazardous waste management

We comprehensively incorporate hazardous waste management content throughout the chemical laboratory course, integrating it seamlessly into the curriculum rather than treating it as a standalone topic [7]. During the experimental preparation phase, students are tasked with investigating the types, properties, and hazards of potentially generated hazardous waste specific to the experiment. They are also expected to familiarize themselves with the relevant treatment methods and discharge standards. For instance, prior to performing the experiment to determine iron content using the potassium dichromate method, students should acquire an understanding of the toxic characteristics of chromium-containing waste solutions and the principles underlying the reduction-precipitation treatment method.

Throughout the experimental operation phase, the systematic classification of hazardous waste is incorporated as an essential element of the experimental protocol. Each laboratory workstation is furnished with designated containers for the segregation of waste liquids, necessitating that students categorize and dispose of waste according to its specific properties (e.g., acidic, alkaline, organic, heavy metal-containing, etc.). Furthermore, the experimental instruction manual delineates the potential types of waste produced at each stage of the procedure and prescribes the appropriate disposal methods. This approach ensures that hazardous waste management is seamlessly integrated into the experimental process.

In the concluding phase of the experiment, it is imperative to establish a specialized section for hazardous waste treatment. For waste liquids characterized by well-defined compositions and uncomplicated treatment processes—such as the neutralization of acid-base waste solutions or the reduction-precipitation treatment of chromium-containing waste solutions—students should undertake the preliminary treatment within a laboratory setting. Conversely, for complex hazardous wastes necessitating specialized treatment, students should be instructed to adhere to standardized procedures involving classification, packaging, labeling, and documentation prior to transferring the waste to professional treatment facilities.

During the extension teaching phase, specialized experiments focusing on hazardous waste treatment are incorporated into the curriculum. For instance, an experimental project entitled "Recycling of Chromium-containing Waste Solutions and Evaluation of Their Efficiency" is crafted to guide students through the comprehensive scientific research process, encompassing literature review, experimental design, and empirical validation. Similarly, an experiment named "Distillation and Recovery of Laboratory Organic Solvents" is structured to provide students with practical experience in resource recycling methodologies.

3.3 Innovating the "Four-Dimensional Integration" Teaching Model

To improve teaching efficacy, we have devised a four-dimensional integrated teaching model that amalgamates "theoretical lectures, case studies, practical training, and virtual simulation" [2,6]. **Theoretical Lectures** are designed to impart foundational knowledge on hazardous waste, encompassing topics such as classification systems, hazard characteristics, pertinent laws and regulations, and common treatment methodologies. These lectures are strategically aligned with experimental course content to prevent purely didactic instruction that may lack practical applicability. **Case Study Session:** This session employs real-world laboratory safety incidents as case studies to facilitate student analyze the causes of accidents and the exploration of preventive strategies. For instance, by examining a case involving an explosion at a university caused by the improper mixing of waste liquids, the session aims to deepen students' comprehension of the critical importance of standardized classification and collection procedures. Similarly, through discussions on incidents where cyanide-containing waste liquids were inadvertently combined with acids, leading to the production of highly toxic hydrogen cyanide gas, the session enhances students' awareness of the compatibility issues associated with hazardous waste. **Practical Training** serves as the fundamental element of the instructional framework. Within each experimental project, we have meticulously developed specific operational procedures for the management of hazardous waste, necessitating that students engage in practical tasks, such as waste liquid classification, neutralization, precipitation, and filtration-under the supervision of instructors. For organic waste liquids produced during large-scale instrumental analysis experiments, students are organized to perform solvent recovery experiments. This "learning by doing" methodology facilitates the effective internalization of hazardous waste management skills, thereby enhancing students' experimental literacy. **Virtual simulation** serves as a critical tool for addressing scenarios that are challenging to replicate in real-world experimental settings. For example, in high-risk operations involving the leakage of highly toxic substances or the disposal of radioactive waste, virtual simulation experiments provide students with the opportunity to engage in the comprehensive emergency response process. Furthermore, virtual simulation platforms can be utilized for training in hazardous waste classification, allowing students to practice the identification and proper classification of various types of waste liquids within a controlled virtual environment.

3.4 Deep Integration of Ideological and Political Elements into Courses

Hazardous waste management and safety education inherently encompass a wealth of ideological and political educational resources. In our pedagogical practice, we have seamlessly integrated the following ideological and political components[3]:

The concept of Ecological Civilization and Sustainable Development emphasizes that "lucid waters and lush mountains are invaluable assets." By highlighting the significant harm of even small quantities of laboratory hazardous waste, it instills in students the responsibility to protect the environment. Additionally, it showcases China's strong commitment to ecological progress through its evolving legal framework for hazardous waste management.

The Scientific Spirit and Professional Ethics: In the case study session, emphasis is placed on the necessity of conducting scientific research within the framework of safety and adherence to established norms. This approach is designed to guide students to understand that a rigorous experimental attitude and adherence to standardized procedures are not only reflections of the scientific spirit but also expressions of responsibility toward the safety of both their own lives and those of others.

Social Responsibility and Rule-of-Law Awareness: Through the elucidation of pertinent laws and regulations, such as the Law on the Prevention and Control of Environmental Pollution by Solid Waste and the Regulations on the Safety Management of Hazardous Chemicals, this initiative seeks to cultivate students' awareness of the rule of law and their sense of social responsibility. It underscores the importance of recognizing that the standardized disposal of laboratory waste is not a discretionary choice but a mandatory legal obligation and a fundamental social responsibility.

The notion of a green development philosophy, coupled with the spirit of innovation, is emphasized in experiments focused on hazardous waste recycling. In these experiments, students are encouraged to contemplate the importance of resource circularity and are motivated to cultivate an interest in pioneering green chemistry experiments.

3.5 Establishing a comprehensive, multi-dimensional performance evaluation system across the entire process

Assessment and evaluation function as essential mechanisms for safeguarding teaching reform. By adopting the concept of "integrated teaching and assessment," we have developed a comprehensive, multi-dimensional assessment and evaluation system that encompasses the entire experimental process[6].

The Daily Assessment, accounting for 40% of the total grade, consists of: preparatory report quality (10%), accuracy in hazardous waste classification and collection (15%), completeness and standardization of experimental records (10%), and classroom participation with safety and environmental awareness (5%).

The Special Assessment for Hazardous Waste Treatment, accounting for 20% of the final grade, is a key part of this reform. Students will conduct 2-3 experiments on hazardous waste treatment during the semester to evaluate their skills in designing treatment plans, creating protocols, and assessing effectiveness. The assessment includes both individual and group evaluations.

The Final Comprehensive Assessment, accounting for 40% of the total grade, is divided into a theoretical examination (20%) and an experimental practical examination (20%). The theoretical examination includes a specific module on hazardous waste management and safety knowledge, while the experimental practical examination requires the completion of essential operational tasks related to hazardous waste treatment.

Process-Based Assessment and Ideological and Political Education Evaluation: In addition to quantitative assessments, process-based evaluations are crucial in ideological and political education. Classroom observations track students' safety habits, environmental behaviors, and teamwork. Reflective writing in reports assesses their understanding of safety and environmental concepts. A semester-end questionnaire gauges changes in students' safety awareness.

4. Teaching Practice Outcomes and Analysis

Following two rounds of teaching practice (involving 120-plus students across four classes in the Biotechnology major), the reform plan has yielded remarkable results.

4.1 Awareness of hazardous waste disposal regulations has been significantly enhanced

Before the reform, students often carelessly disposed of waste liquids after experiments, showing poor understanding of hazardous waste classification. After the reform, their classification accuracy for hazardous waste improved from below 50% to over 85%. Now, most students can accurately identify different waste liquids-acidic, alkaline, organic, and heavy metal-and perform the required labeling and documentation.[1].

4.2 Safety and environmental awareness has significantly improved

The survey results showed that 92% of students believe integrating hazardous waste management into lab teaching enhances their understanding of environmental risks. Moreover, 88% intend to follow waste disposal regulations in future experiments. Some students admitted they previously underestimated the importance of lab waste disposal, now recognizing that individual negligence can lead to significant problems[6].

4.3 The educational effects of ideological and political education through curriculum are beginning to take shape

The incorporation of ideological and political education into waste management and safety education courses has markedly enhanced students' sense of social responsibility and legal awareness. In their final course summaries, over 80% of students actively engaged in themes such as ecological civilization and sustainable development. Furthermore, some students independently initiated "Green Laboratory" activities, which have fostered a positive exemplary effect within the department[3-4].

4.4 Dissemination of Teaching Reform Experiences

The reform's insights have been extended to other departmental lab courses, like Organic Chemistry and Biochemistry, which now include similar hazardous waste management modules. These instructional cases have also been integrated into the university's "Curriculum-based Ideological and Political Education Demonstration Project," guiding pedagogical reforms in similar courses[1].

5. Conclusion

Effective hazardous waste management and safety education are essential in chemical lab instruction for Biotechnology majors. This paper illustrates that integrating waste management into lab courses involves more than just adding a "waste liquid treatment" section. It requires a comprehensive instructional design that encompasses teaching objectives, content, models, ideological and political education, and assessment methods[8].

The four-dimensional teaching model, which includes theoretical instruction, case discussions, practical training, and virtual simulation, equips students with the necessary skills for hazardous waste treatment while instilling safety, environmental awareness, and standardized practices. By embedding ideological and political elements, the curriculum fosters social responsibility and legal awareness. Continuous, multi-faceted assessments throughout the learning process reinforce safe behaviors[9].

Teaching reform is advancing, and we plan to integrate virtual simulation technology into hazardous waste treatment education, develop real-world experimental projects, and establish cross-course collaboration in hazardous waste management. This will embed safety and environmental education in biotechnology programs, fostering professionals with strong safety awareness, environmental literacy, and social responsibility[10].

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