Research on Teaching Reform of Laboratory Safety Education under the Background of Inheritance and Innovation of Traditional Chinese Medicine

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Abstract: *Under the deepening context of inheriting and innovating Traditional Chinese Medicine, the complexity of its research subjects, the composite nature of its methodologies, and the particularity of its cognitive framework have raised an urgent demand for the disciplinary reconstruction of laboratory safety education. Addressing the gap between the current general-purpose model and the specific needs of the discipline, this study proposes reshaping the objective system with a core focus on risk prevention and control capabilities. It constructs a curriculum that integrates Traditional Chinese Medicine thinking and scenario-based modules, and promotes diversified teaching methods such as case study analysis and project-based learning. Furthermore, it establishes a multi-dimensional evaluation index system that combines process and outcome, along with a dynamic optimization mechanism. Finally, the study demonstrates a pathway for building a long-term safety education ecosystem through culture-institution synergy, providing a theoretical reference for establishing a laboratory safety teaching system that supports the innovative development of Traditional Chinese Medicine.*

Keywords: *Traditional Chinese Medicine laboratory; safety education; teaching reform; risk prevention and control; inheritance and innovation; competency-oriented approach*

Introduction

Under the background of inheritance and innovation in Traditional Chinese Medicine, its experimental activities are confronted with an increasingly complex and discipline-specific risk spectrum due to the uniqueness of its materials, methodologies, and knowledge systems. The current safety education model, primarily adapted from general science and engineering disciplines, exhibits a disconnection in content from the unique risk scenarios specific to Traditional Chinese Medicine. In terms of methodology, it overemphasizes knowledge imparting while neglecting capability development; in evaluation, it struggles to effectively assess actual risk response behaviors. This disconnect constrains protective efficacy and also hinders the internalization of safety awareness into researchers' professional competence. Therefore, conducting systematic research on teaching reform based on the discipline's internal logic holds significant theoretical and practical importance for constructing a talent development system that aligns with the advancement of Traditional Chinese Medicine and ensures the safety and robustness of scientific research activities.

1. Analysis of the Connotation and Characteristics of Laboratory Safety Education in Traditional Chinese Medicine

1.1 The Particularity of Laboratory Safety from the Perspective of Traditional Chinese Medicine Discipline

The laboratory safety system in Traditional Chinese Medicine is rooted in its unique disciplinary attributes and research paradigms. Its particularity is first reflected in the complexity of the research subjects and materials. Experiments often involve raw medicinal materials derived from plants, animals, and minerals, which possess diverse components and non-uniform physicochemical properties. During processes such as pretreatment, extraction, and processing, these materials may generate unintended reactions or toxic volatiles distinct from conventional chemical reagents. Secondly, the composite nature of research methodologies constitutes another defining feature. Laboratory activities frequently integrate multiple technical pathways, including chemical extraction, biological effect evaluation, and even simulations of traditional preparation techniques. This integration causes risk sources to extend and intersect across multiple dimensions-from mere chemical storage to bioactivity testing, high-temperature and high-pressure processing, as well as animal experiment ethics and biosafety. Finally, the difference in cognitive frameworks cannot be overlooked. Research guided by Traditional Chinese Medicine theory sometimes requires its design logic and risk assessment to balance traditional empirical knowledge with modern scientific norms. For instance, understanding "toxicity" necessitates establishing connections and translations between traditional medicinal property theories (such as high toxicity or low toxicity) and modern toxicological indicators. This demands that safety cognition possess corresponding disciplinary translational capacity.

1.2 The Inherent Requirements for Safety Education from Traditional Inheritance and Modern Innovation

Inheritance and innovation, serving as the dual threads in the development of Traditional Chinese Medicine, impose differentiated internal stipulations on laboratory safety education. The dimension of traditional inheritance requires safety education to encompass the distillation of risk-related historical experience. Empirical knowledge accumulated from ancient practices of Chinese herbal processing and preparation-such as heat control, medicinal compatibility contraindications, and the handling of particularly toxic medicinal substances-must be interpreted and translated through modern safety science. This process aims to formulate teachable and operational safety protocols, ensuring the safe continuation of empirical wisdom within the laboratory environment. The dimension of modern innovation, conversely, strongly demands that safety education keeps pace with cutting-edge research developments. With the widespread application of omics technologies, molecular network pharmacology, and high-end precision analytical instruments in Traditional Chinese Medicine research, laboratories are introducing new physical, chemical, and biological hazards. Safety education must prospectively cover the standard operating procedures, potential risks, and emergency responses associated with these new technologies and equipment. It must also cultivate in students the mindset to identify and assess unknown risks emerging from interdisciplinary research. Together, these two dimensions necessitate that the safety education system possesses characteristics of dynamic evolution and knowledge integration[1].

1.3 An Examination of the Adaptability Between Current Safety Education Models and Discipline Development Needs

Several gaps warrant examination between the currently prevalent laboratory safety education models and the rapidly evolving needs of the Traditional Chinese Medicine discipline. From the perspective of content structure, most safety education programs are derived from general science and engineering templates. They primarily focus on conventional chemical management, fire escape procedures, and basic instrument operation, yet fail to adequately incorporate experimental scenarios unique to Traditional Chinese Medicine. Examples of such omissions include pressure vessel safety during herbal decoction processes, the risk of dust explosions, or biosafety issues related to medicated substance handling in animal experiments. In terms of knowledge delivery methods, the existing models often lean towards the one-way indoctrination of rules and fragmented skill training. They lack systematic integration of safety awareness into the complete chain of scientific research training, spanning from project design and experimental operation to data processing. The separation of teaching from research activities prevents safety cognition from being internalized as researchers' instinctive awareness and behavioral patterns. Upon further examination, the evaluation of educational effectiveness is typically confined to written exams or attendance records. There is a lack of an in-depth assessment mechanism for evaluating risk decision-making capabilities and the effectiveness of safety behaviors within the real, complex, and non-standardized experimental environments characteristic of Traditional Chinese Medicine. This limitation in adaptability calls for an education reform that is more discipline-targeted, systematically integrated, and competency-oriented.

2. Reconstruction of Laboratory Safety Education Concepts Oriented Towards Inheritance and Innovation

2.1 Reshaping the Educational Objective System with Risk Prevention and Control at Its Core

2.1.1 Cultivating Systemic Risk Identification and Assessment Capabilities

The core objective is to enable students to move beyond the recognition of isolated hazards and master methods for conducting systemic risk analysis of complete experimental processes. This includes guiding students to utilize tools such as process decomposition and fault tree analysis to perform predictive risk scanning of the entire workflow chain-from herbal material preprocessing and complex extraction and separation to efficacy and toxicology evaluation. It focuses on cultivating their sensitivity to cross-disciplinary risk coupling (e.g., the superposition of chemical toxicity and biological infection risks), as well as their logical reasoning and preliminary assessment capabilities regarding potential unknown risks in non-routine operations and exploratory research. This objective emphasizes the proactivity and comprehensiveness of risk perception[2].

2.1.2 Setting Tiered and Precise Risk Management and Control Objectives

The educational objectives must establish a clear progression of capabilities based on the learning stage and research level. The primary stage objective is focused on compliance with both general and Traditional Chinese Medicine-specific safety protocols (such as the management standards for toxic medicinal materials), ensuring the safety of fundamental operations. The intermediate stage objective then shifts emphasis towards customizing risk control plans for specific research directions (e.g., processing technology research or injectable preparation safety evaluation), enabling learners to independently execute monitoring and emergency responses for conventional risk sources. The advanced stage objective concentrates on the ability to integrate safety considerations from the initial phase of project design, possessing the capacity to conduct original risk assessments and develop protocols for the entire process of newly established research methods, thereby achieving the synchronous design of risk prevention and control with scientific research innovation.

2.1.3 Outcome Evaluation Oriented Towards Behavior and Decision-Making

An objective system centered on risk prevention and control inherently necessitates an innovation in the methods used to evaluate educational effectiveness. The focus of evaluation should shift from written exam scores to the observation and analysis of learners' safety behaviors and risk decisions within simulated or real experimental situations. This involves utilizing assessment tools such as scenario simulation tests, experimental video analysis, and safety audit report writing to comprehensively examine the acuity of their risk identification, the appropriateness of their control measures, and the rationality of their emergency response. This shift in evaluation orientation aims to establish an objective chain of evidence for competency attainment, driving both instructors and learners to focus collectively on the substantive development of risk prevention and control capabilities.

2.2 Restructuring Safety Course Content by Integrating Traditional Chinese Medicine Thinking

2.2.1 Modular and Scenario-based Integrated Content Design

The course content should abandon the conventional practice of categorization by safety type (e.g., fire safety, chemical safety) and instead be organized around typical Traditional Chinese Medicine research modules. For example, establishing a module on "Safety in Herbal Extraction, Separation, and Purification Experiments" would organically integrate content on organic solvent safety, pressurized/vacuum operation safety, and specific risks such as the photosensitivity or pyrophoricity of certain natural products. Setting up a module on "Safety in Pharmaceutical Formulation and Preparation Process Experiments" would then focus on dust explosion prevention, operations in high-temperature and high-humidity environments, equipment-related mechanical hazards, and potential cross-contamination control. This design ensures that students acquire a complete, contextually matched package of safety knowledge from the very beginning of their exposure to specialized experiments.

2.2.2 Disciplinary Expansion and Deepening of Traditional Safety Concepts

It is necessary to develop and teach specialized safety concepts and standards tailored to the unique materials and methodologies of Traditional Chinese Medicine laboratories. For instance, this involves establishing a "Risk Classification Standard for Medicinal Material Handling" based on the integration of Traditional Chinese Medicine medicinal property theory (such as high toxicity or toxicity) and modern toxicological data. It also includes explaining "Protection against Nano-scale Heavy Metal Dust" during the processing of mineral-based medicinal substances, and analyzing the potential "Risk of Bioaerosol and Antimicrobial Resistance Dissemination" that may arise from biological fermentation or in vivo metabolism experiments. This content deepens and expands general safety principles in accordance with disciplinary characteristics, thereby addressing gaps in the current knowledge system.

2.2.3 The Transdisciplinary Translation and Integration of Traditional Empirical Knowledge into Safety Science

The curriculum must undertake the function of translating the safety wisdom embedded within the empirical traditions of Traditional Chinese Medicine into modern scientific terms. This involves systematically reviewing classical texts for records concerning processing methods to reduce toxicity, compatibility contraindications, and administration precautions. By applying modern chemistry, pharmacology, and analytical techniques, the curriculum should elucidate the underlying safety science principles-such as altering the structure of toxic components through processing or reducing organ-specific damage through specific herbal combinations. Incorporating such validated "empirical-to-scientific" transformation cases into the teaching content not only enriches the historical and cultural dimension of safety knowledge but, more importantly, enables students to comprehend the deep-seated logic behind safety protocols. This understanding enhances their conscientiousness in both adhering to and innovating upon these standards[3].

2.3 Innovation of Diversified Teaching Methods Based on a Competency-Oriented Approach

2.3.1 In-Depth Application of Case Study Analysis and Scenario Simulation

Representative real-life incidents or potential risk scenarios from Traditional Chinese Medicine laboratories are meticulously selected and developed into structured teaching cases. Students are guided to conduct in-depth analysis in small groups, completing comprehensive training that spans from reconstructing the incident sequence and tracing the root causes (using tools such as fishbone diagrams and the Swiss cheese model) to proposing systemic corrective measures. Concurrently, high-fidelity scenario simulations and virtual simulation technology are extensively applied to construct complex, high-risk, low-probability emergency scenarios. Examples include "Sudden Contamination in an Aseptic Laboratory for Chinese Medicine Injections" and "Suspected Cross-Contamination Incident Between an Experimental Animal Facility and a Cell Culture Room." These simulations allow students to engage in decision-making and operational drills within highly realistic, high-pressure environments, thereby honing their on-the-spot judgment and team-based collaborative response capabilities.

2.3.2 Integration of Project-Based Learning with Full-Process Safety Risk Assessment

The concept of Project-Based Learning should be systematically introduced into the research training of graduate students. Students are required to independently complete a detailed Safety Risk Assessment and Prevention & Control Plan for the Experimental Project for their self-initiated or assigned research projects. This plan must serve as an essential component of the research proposal or experimental protocol approval process. Supervising instructors are responsible for reviewing and providing feedback on the plan's professionalism, comprehensiveness, and feasibility. This process seamlessly embeds safety education into the main trajectory of scientific research, compelling students to proactively assume primary responsibility for safety from the very outset of research planning. It also enables them to comprehensively apply skills in risk identification, assessment, and management within a practical context.

2.3.3 Fostering the Routine Integration of Embedded Teaching and a Research Community

It is essential to promote the transformation of safety education from centralized, course-based activities into routine elements permeating daily research practice. This can be achieved by designating a fixed segment within laboratory group meetings to discuss potential safety hazards in recent experiments or to share safety alerts; by incorporating a review of the safety compliance of research methods into literature presentation sessions; and by encouraging senior students to pass on their safety operation experience for specific equipment or techniques to newcomers. By cultivating a laboratory culture and research community atmosphere where "everyone emphasizes safety and every task prioritizes safety," the development of safety awareness becomes a continuous, immersive process, ultimately solidifying into the professional habits and innate literacy of researchers[4].

3. Effectiveness Assessment and Continuous Improvement Mechanism for the Educational Reform

3.1 Construction of a Multi-dimensional Evaluation Index System for Laboratory Safety Education Quality

The assessment of the effectiveness of safety education reform must move beyond singular metrics such as examination pass rates or accident statistics. Instead, it necessitates the establishment of a multi-dimensional evaluation system capable of comprehensively capturing competency development and behavioral changes. This system should integrate both process evaluation and outcome evaluation, focusing on key aspects of teaching implementation as well as measuring the ultimate output of safety literacy. Process indicators may encompass the disciplinary relevance of course content, the interactivity and challenge level of teaching methods, and the specialization level of the teaching staff. Outcome indicators, on the other hand, need to focus on learners' level of safety awareness, the quality of their risk decision-making in both simulated and real experimental environments, the compliance and standardization of their safety operation behaviors, as well as their willingness and ability to proactively identify and report potential hazards. Together, these indicators form a three-dimensional assessment network, providing empirical evidence for the effectiveness of the reform.

The construction of this evaluation index system requires the introduction of mixed research methods. Quantitative tools, such as safety knowledge-attitude-practice scales that have undergone reliability and validity testing, situational judgment test scores, and laboratory safety audit data, can provide macro-level trends and group comparisons. Qualitative methods, such as in-depth interviews with students, participatory observation of experimental processes, and reflective textual analysis, can deeply reveal the complex process of safety cognition internalization, the decision-making logic behind behaviors, and underlying obstacles within the teaching process. Through the triangulation of quantitative and qualitative data, the evaluation system can more accurately and profoundly reflect the true efficacy of the educational reform, thereby providing precise guidance for subsequent optimization.

3.2 Establishment of a Teaching Feedback and Dynamic Optimization Mechanism

A teaching ecosystem capable of continuous self-improvement relies on a stable, unobstructed, and actionable teaching feedback loop. The design of this mechanism must ensure that feedback information is sourced from multiple stakeholders and permeates the entire process-before, during, and after instruction[5]. Feedback prior to instruction is primarily obtained through needs analysis. For instance, conducting a prospective risk assessment for upcoming research projects can help identify gaps or weaknesses in the safety education curriculum. Feedback during instruction is collected in real-time from classroom interactions, simulation drills, and project-based learning activities. This captures students' comprehension difficulties, skill deficits, and their responses to the teaching methodologies employed.

Establishing a mechanized process for handling and converting feedback is crucial. The various types of collected feedback information must undergo systematic analysis, attribution, and priority ranking by a designated teaching research group. Based on the analytical conclusions, specific optimization suggestions for course content, teaching methods, or evaluation approaches should be formulated, accompanied by clear revision deadlines and designated responsible personnel for implementation. The core of this mechanism lies in transforming scattered feedback into structured, actionable improvement plans, thereby forming a closed loop from "feedback collection → analysis and diagnosis → plan formulation → implementation and revision → effectiveness re-evaluation." By institutionalizing this dynamic cycle, the safety education system can break free from static rigidity and evolve into a self-adaptive system capable of continuous advancement alongside disciplinary development, technological progress, and the deepening of cognitive understanding.

3.3 Construction of a Safety Education Ecosystem Supported by Long-term Mechanisms

The sustainability of educational reform cannot rely solely on periodic projects or external impetus. Ultimately, it must be grounded in the construction of a safety education ecosystem possessing endogenous motivation and a supportive structure. The cornerstone of this ecosystem is the deep integration of culture and institution. At the cultural level, it is necessary to cultivate safety values centered on "risk pre-control, shared responsibility, and rigor and practicality" within laboratories and research teams, transforming them into informal norms widely recognized by the academic community. At the institutional level, the validated educational objectives, curriculum modules, teaching methods, and evaluation systems must be solidified into stable teaching management documents, talent training program requirements, and resource allocation standards. This institutionalization provides a rigid guarantee for the routine implementation of safety education[6].

The vitality of the ecosystem stems from the synergy and resource convergence within a multi-actor network. This necessitates moving beyond the traditional perception of safety education as the sole responsibility of a single department, instead fostering the deep involvement and shared responsibility of diverse stakeholders including professional course instructors, laboratory technical managers, graduate supervisors, and students. Establishing regular communication platforms facilitates the flow of knowledge and the sharing of experiences between safety education, cutting-edge developments in professional education, and best practices in laboratory management. Sustained resource investment and optimized allocation are crucial for maintaining the ecosystem, encompassing the continuous training of teaching staff, the iterative updating of teaching case databases and simulation platforms, and policy guidance that incentivizes both teachers and students to engage in innovative safety education activities. Only by constructing such an ecosystem-guided by culture, secured by institutions, synergized by multiple actors, and supported by resources-can Traditional Chinese Medicine laboratory safety education gain an inexhaustible driving force for development. Thereby, it will provide a solid and enduring safety cornerstone for the cause of inheriting and innovating Traditional Chinese Medicine.

Conclusion

Through a systematic examination of the connotation, characteristics, conceptual reconstruction, and effectiveness mechanisms of laboratory safety education in Traditional Chinese Medicine, this study demonstrates the inevitable path of teaching reform oriented towards inheritance and innovation. The core of this reform lies in shifting safety education from an external, generic indoctrination of knowledge towards a competency cultivation deeply integrated with Traditional Chinese Medicine research practice, guided by the generation of risk prevention and control capabilities. This is concretely manifested as being led by the objectives of systemic risk identification and tiered management, carried through modular and discipline-specific content reconstruction, and implemented via contextualized and embedded innovations in teaching methodology. To ensure the sustained effectiveness of the reform, it is imperative to establish a multi-dimensional evaluation index system coupled with a dynamic feedback and optimization mechanism, and to commit to fostering a long-term education ecosystem that integrates safety culture, robust institutions, and multi-stakeholder collaboration. Future research in this field could further focus on the long-term tracking and empirical validation of educational outcomes, the extraction of cross-institutional best practice models, and the expansion and deepening of teaching scenarios empowered by new technologies such as artificial intelligence and virtual reality. This will propel the continuous improvement and adaptive development of the Traditional Chinese Medicine laboratory safety education system.

Fund Projects

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