

Exploration and Practice of University Laboratory Safety Control System in Digital Transformation

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Abstract: The ongoing in-depth implementation of digital transformation in education offers a new path and opportunity for improving university laboratory safety control systems. In the current era, three main security risks exist in university laboratories. First, the inadequate implementation of system norms makes it difficult to address security risks. Second, safety education is insufficient, with both teachers and students lacking essential safety knowledge and skills. Third, safety facilities are incomplete, leading to an unstable safety foundation. To address these issues, this article proposes the establishment of a “three-combination” laboratory safety control system, based on a digital platform integrating management, education, and infrastructure. This approach utilizes the digital laboratory management platform to strengthen management practices, enhance safety education, improve environmental conditions, and effectively reduce laboratory safety risks. Lastly, the paper provides a brief overview of the practical implementation and outcomes of the digital laboratory safety control system in schools.

Keywords: Digital transformation of education; Laboratory safety; Safety management; Safety education; Safety construction

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1. Introduction

University laboratories are crucial hubs for scientific research, innovation, and personnel training. Laboratory safety is vital to safeguarding the lives and property of university faculty and students, as well as advancing the nation’s strategy of rejuvenating the country through science and education. Currently, global competition in science and technology is intensifying, and China’s focus on the “four new constructions” in education and the development of “new quality productivity” is deepening. With the rapid expansion of laboratory spaces, experimental equipment, and the number of participants, laboratory safety risks are escalating. In recent years, despite numerous efforts by government agencies and educational institutions to improve systems, strengthen safety inspections, and implement safety education, laboratory safety accidents still occur intermittently. These

accidents are often marked by a low frequency but significant losses, difficult resolution of contributing factors, wide social impact, academic setbacks, and are primarily caused by human error^[1]. Fire and explosion accidents are the most prevalent in this context. Researchers use association rules to dig and find the factors causing accidents, which are laboratory supervision and management, safety responsibility, safety habits, storage of experimental items, and safety awareness^[2]. At present, the digital transformation of education is advancing in-depth, providing a new path and opportunity for the construction and improvement of laboratory safety control systems in universities. Therefore, this study aims at the main causes of laboratory safety accidents and explores the construction of a university laboratory safety control system.

2. The security risks of university laboratories

2.1. The implementation of system norms is inadequate, and the resolution of hidden safety risks is difficult

Since the Ministry of Education initiated the national laboratory safety inspection in 2015, a series of documents have been issued to strengthen and standardize laboratory safety in universities. These include the “Opinions of the Ministry of Education on Strengthening Laboratory Safety in Colleges and Universities”, the “Notice of the General Office of the Ministry of Education on Carrying Out Special Actions to Strengthen Laboratory Safety in Colleges and Universities”, the “Code for Laboratory Safety in Colleges and Universities”, and the “Code for Laboratory Fire Safety Management in Colleges and Universities”. These measures aim to provide clear guidelines and regulations to enhance laboratory safety management, promote standardized practices, and ensure the protection of both personnel and facilities in university laboratories.

Despite these efforts, challenges in the full implementation and enforcement of safety protocols still remain. Provincial government education departments and universities have also developed regulations and established systems to improve safety management, including the implementation of a safety responsibility system. A survey conducted across 38 domestic colleges and universities reveals that most institutions have adopted a “three-level linkage” safety management system^[3]. However, the results of special inspections and self-assessments in colleges and universities reveal that the implementation of system norms remains inadequate. Issues such as the control of hazardous chemicals, cylinder gas safety, and fire safety regulations continue to persist, often resulting in a “rectification–recurrence” cycle^[4-5]. The effective implementation of laboratory safety management systems and norms ultimately depends on people. The failure to implement these norms effectively can be attributed to two key factors. First, managers lack efficient and intelligent tools to ensure layered implementation and monitoring. Second, there is a lack of enhanced awareness among teachers and students regarding safety responsibilities, which leads to weak responsibility consolidation, low enthusiasm, and insufficient internal motivation to actively engage in safety practices.

2.2. Safety education is insufficient, and teachers and students lack safety knowledge and skills

To understand the cognitive and behavioral status of students’ laboratory safety, Xu *et al.* surveyed 1,571 students in Southeast University and found that even after receiving safety education and participating in laboratory experiment activities, the mastery of safety knowledge and skills was still not satisfactory^[6]. Similarly, to understand the state of laboratory safety education in universities under the new engineering paradigm, Peng *et al.* surveyed 98 universities in China and found that there are prominent problems in the construction, operation

and enforcement of laboratory safety education responsibility system in Chinese universities ^[7].

The inadequacy of laboratory safety education in universities can be attributed to both objective and subjective factors. On the one hand, challenges such as the complexity of laboratory safety education, the heavy demands of laboratory teaching and research, and the shortage of qualified teachers and resources contribute to the problem. On the other hand, the rigidity of teaching modes and the ineffective implementation of assessment and access protocols exacerbate the issue, leading to poor teaching outcomes and insufficient safety preparedness among students and faculty.

2.3. The safety facilities are incomplete, and the foundation of laboratory safety is weak

Many Chinese universities, particularly those in the western regions, have not adequately invested in laboratory safety infrastructure, and the existing conditions are often insufficient. Numerous universities, especially those with long histories, house laboratories in old buildings with aging pipelines. With the continuous update and increase of experimental equipment, the electricity load increases, and the safety hazards continue to intensify. A study by Guo *et al.*, which surveyed 54 universities in Shaanxi Province, found significant gaps in laboratory safety practices. Specifically, 16 universities (29.6%) did not provide safety publicity or training, nor did they allocate regular funds for safety facilities. Furthermore, 23 universities (42.6%) had issues with safety warning signs, with non-standard or missing safety information. Additionally, 26 universities (48.1%) lacked properly equipped and maintained safety and first-aid facilities such as emergency sprays, eye washes, first-aid kits, and fire equipment, while 18 universities (33.3%) had not even initiated laboratory safety information construction ^[8]. Due to differences in development basis and location, the construction and improvement of laboratory safety facilities in colleges and universities is unbalanced and inadequate, with a big gap in the relevant standards and requirements of laboratory safety work.

3. The construction of laboratory safety control system based on digital platform

Currently, with the rise of digital China and the accelerated digital transformation of education, the development of digital campuses is rapidly advancing. This transformation enables the establishment of a digital laboratory safety control system, which is becoming an inevitable trend. Based on system theory, laboratory safety control system is a complex system, including safety management, safety construction, safety education, and other interrelated businesses. The digital management platform can integrate various resources and activity information to provide technical support for system operation. Drawing from cybernetics, by monitoring and analyzing laboratory operations, laboratory managers at various levels can quickly identify potential risk points, implement preventive measures, or optimize processes to enhance both safety and efficiency ^[9]. Therefore, this study proposes the construction of a laboratory safety control system that integrates the strengths of traditional safety management methods, while prioritizing laboratory safety as the core goal and the protection of teachers' and students' lives and property as the central value. This system is underpinned by a "three-combination" approach, which merges management, education, and construction, supported by a digital platform.

3.1 Build a digital laboratory management platform to strengthen safety management

Yang *et al.* emphasized that laboratory safety management at various levels requires sufficient, timely, and necessary safety information to ensure the correct execution of safety prediction, decision-making, and implementation at each stage of the causative chain. This ensures that potential accident chains are effectively prevented or disrupted ^[10].

To address this, colleges and universities should develop a digital laboratory management platform that integrates critical information such as laboratory spatial data, experimental equipment details, experimental curriculum data, project specifics, and personnel information. By collecting and analyzing this data, the platform can generate big data related to laboratory safety, enabling accurate identification of security risks through data mining technology. This, in turn, supports intelligent decision-making in safety management and the enforcement of safety systems and norms.

The digital laboratory management platform includes infrastructure, network architecture, and application system. Infrastructure includes the computer network, access control system, power management system, monitoring systems, and other fundamental technologies. The modern network architecture, which is based on AI, cloud computing, and big data, improves data processing capabilities and provides robust data support for laboratory teaching and research activities. Additionally, various application systems facilitate the management of laboratory operations. For instance, Southeast University has implemented the “Experimental Materials and Chemicals Management Platform”, which enables comprehensive supervision and management of experimental consumables, covering the entire process from procurement and review to usage and settlement ^[11].

3.2. Optimize the evaluation system and mechanism to stimulate the vitality of grass-roots staff

William James, a professor at Harvard University in the United States, found that the absence of proper incentives, individuals can only utilize 20% to 30% of their potential, but with full stimulation, they can reach 80% to 90% of their capabilities ^[12]. To fully stimulate the enthusiasm of laboratory managers, laboratory teachers, laboratory technicians, and other grass-roots, colleges and universities must improve and optimize their evaluation systems, including title evaluations, job appointments, and performance appraisals. These systems should directly link job titles, career development, job benefits, and the implementation of laboratory safety standards, daily management, and safety education participation.

The development of a digital and intelligent laboratory management platform can facilitate the recording of the daily work processes of all personnel. The platform can also generate periodic reports as required. By establishing and refining a system that combines both incentives and penalties, universities can activate the intrinsic motivation of grassroots management and technical personnel, thereby ensuring the effective implementation of laboratory safety standards and fostering a culture of safety within the laboratory environment.

3.3. Promote the high-quality development of safety education and improve the effectiveness of safety education

In line with relevant laws and administrative requirements, it is the legal responsibility of universities to organize and conduct safety education, while it is equally the legal obligation of both teachers and students to engage in safety education ^[13]. As early as in 2021, the General Office of the Ministry of Education put forward the requirement that “universities should build a laboratory safety education system and incorporate laboratory safety education into the training of students” and that “personnel who have not obtained corresponding credits or failed to pass the examination shall not enter the laboratory for experimental operation”.

However, universities often face limitations due to basic conditions and traditional laboratory management methods, resulting in challenges with implementing strict access control systems and ensuring safety education compliance. For instance, laboratory access control systems and safety education examinations are often not well-integrated.

To address these challenges, universities should focus on building an online education platform that offers comprehensive and rich teaching resources. This will allow for customized and personalized laboratory safety education, enhancing the practicality and accessibility of safety training. Additionally, with the ongoing development of digital campuses, it is essential to create a seamless linkage between the safety education examination system and other key systems, such as laboratory use reservations, award and grant systems, and project declarations.

3.4. Increase investment in improving environmental facilities and consolidate the foundation of laboratory safety

A safe environment and facilities are the fundamental prerequisites for the safe operation of laboratories. For years, universities have prioritized updating experimental equipment but have often overlooked the construction of safety environments and facilities, leading to existing safety hazards^[14]. Furthermore, when new laboratories are built or instruments and equipment are updated, the necessary safety facilities and equipment are frequently excluded from the planning process, creating new safety risks. Additionally, in the course of management reforms and information construction, the establishment of digital management platforms for laboratories has received insufficient attention, and the development of digital intelligent application systems has been inadequate.

To address these challenges, it is essential to first allocate sufficient financial resources at the institutional level to support the rectification of existing safety hazards in laboratory environments. This should include the comprehensive upgrade of current safety infrastructure to address any legacy risks. Furthermore, when constructing new experimental training buildings, it is crucial to standardize the inclusion of safety facilities and equipment to mitigate potential future risks. This should involve installing advanced systems, such as intelligent access control, video surveillance, and intelligent reagent cabinets, all of which can be integrated into a central monitoring and management platform. By connecting these systems to a digital platform, laboratory managers and relevant personnel can gain real-time visibility into the laboratory environment, equipment, and reagent conditions, enabling them to identify and address safety concerns proactively, thus preventing accidents before they occur.

4. The practice and effect of building the laboratory safety control system

The construction of a digital campus is a significant initiative for universities to align with the Chinese government's broader goal of building a digital China. This transformation further supports the national strategic action of digital education, empowering universities with high-quality development through digitalization. To achieve this, the university has developed an overall framework for "1281" digital campus construction^[15]. The university has successfully built a new smart campus infrastructure, represented by the "One Network" and a cloud center computer room. It is also actively promoting the development of various information systems, laying a solid foundation for the laboratory safety control system.

A key aspect of this transformation has been the construction of a digital laboratory management platform. Over the years, the university has developed systems like the "Smart Laboratory Management Platform" and the "Intelligent Laboratory Safety Inspection System" to support the implementation of a three-tier laboratory safety management mechanism across campus. These systems have strengthened intelligent, process-based control over laboratory safety management, safety education, and safety infrastructure.

The university has also worked on enhancing the laboratory safety management system. Efforts include

improving the hierarchical safety management system and establishing a three-level safety management system that spans schools, colleges, and laboratories. Additionally, a routine mechanism has been put in place involving the teaching affairs office, security office, and property management company to jointly conduct safety inspections and rectify any hidden hazards. The university has also introduced senior experimentalist titles and optimized the evaluation of experimental series titles to better align with safety standards and practices.

In terms of safety education, the university has emphasized strengthening laboratory safety education. It has created a “Laboratory Safety Online Learning and Access Examination Platform” and established a “Laboratory Safety Education Training and Access System”. These systems ensure standardized, systematic implementation of safety education across the university. Furthermore, the university has focused on improving laboratory safety infrastructure, including the unified and timely disposal of hazardous laboratory waste. This proactive approach helps stabilize laboratory safety while continuously addressing potential risks.

The university has actively explored and practiced the “three-combination” laboratory safety control system based on the digital platform of management, education and construction, which has achieved the continuous safe and stable operation of the university’s laboratories and won high praise in safety inspections at all levels.

5. Conclusion

Laboratory safety management is a highly complex and significant work. The construction of a “three-combination” risk and hidden danger control system based on the support of digital platform management, education, and construction provides a framework for universities to improve laboratory safety control work. As digital intelligence technologies continue to evolve, laboratories face new challenges that require ongoing research and exploration in areas like safety management, education, and infrastructure development. This continuous effort is essential to adapting to emerging risks and maintaining a high standard of safety.

Disclosure statement

The author declares no conflict of interest

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