ISSN 2522-6398 Vol. 7, Issue 5: 24-30, DOI: 10.25236/FER.2024.070504

Effective Practices of Enhancing Students' Safety Awareness in Teaching Laboratories in the New Era

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Abstract: *This study aims to improve the safety awareness of college students in teaching laboratories through the execution of a laboratory educational reform. Through the use of a two-way mentorship model, the experiment instructor provides safety instruction related to the experiment's subject matter before each class, and the laboratory teaching assistant gradually increases students' awareness of safety as the class moves forward. These approaches integrate traditional safety assessments (such as questionnaires and visual error identification exercises) with advanced techniques in the modern era (such as high-quality safety video tutorials, incorporation of MOOCs, and utilisation of immersive virtual simulation environments), all of which can be successfully applied in biochemistry instructional laboratories. The research findings demonstrated that implementing these particular procedures had a substantial impact on students' comprehension of laboratory safety standards and heightened their consciousness of laboratory safety. We have developed a user-friendly, multi-tiered dual-teacher teaching approach that has been of great help to the cultivation and enhancement of laboratory safety awareness among local higher education students. This method offers practical guidance for incorporating thorough safety education training into regular laboratory courses, thereby improving the safety awareness and practices of college students in teaching laboratories. It is anticipated that this approach will be readily embraced in various educational settings, resulting in substantial prevention of safety risks.*

Keywords: *Laboratory Educational Reform, Safety Awareness, Dual-teacher Leadership, Teaching Laboratories, Undergraduate Students*

1. Introduction

Driven by the national innovation-driven development plan, technological innovation has emerged as a crucial strategic cornerstone for enhancing social productivity and overall national prowess. Universities have been the primary driving force behind national science and technology innovation, consistently advancing fundamental research and high-tech research over the past decade.With a large increase in the number of college entrants, there is also a noticeable surge in the size of laboratories[1]. Laboratories encompass a multitude of intricate dangers, accompanied by frequent human movement, and the challenges and demands confronted by laboratory safety management have significantly intensified.

Research has indicated a strong correlation between university accidents and college students' safety awareness, safety attitudes, and safety behaviour[2]. Hellman[3] conducted a statistical examination of laboratory accident data spanning over 20 years. The findings revealed that 81% of incidents took place in teaching laboratories, with students being the primary cause of most mishaps. Despite the substantial endeavours made by governments and organisations to implement stringent safety regulations and foster a proactive safety mindset[4,5]. Nevertheless, ensuring laboratory safety in higher education settings continues to encounter obstacles. These issues are frequently ascribed to a lack of effective implementation of current safety legislation, insufficient investment in fundamental safety equipment, and a limited level of general safety awareness[6–8]. Research by Bai *et al* [1] has found that the primary cause of laboratory safety accidents is human factors. The level of safety training provided to personnel is currently inadequate. Al-Zyoud *et al* [9] evaluated the knowledge of undergraduate students at the

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German Jordanian University regarding chemical laboratory safety and found that it did not meet the desired standards. The study also highlighted the immediate necessity for well-organized safety education and thorough risk management strategies. According to a survey conducted by Wu Guixiang *et al* [10] at Kunming University of Science and Technology in China, it was discovered that 63.58% of students had a deficient understanding of laboratory safety. He advocated for the implementation of compulsory, extensive, and daily laboratory safety education and training courses as a viable approach to enhance this scenario. The findings of a study by Li *et al* [11] revealed that there is only one kind of safety education course and that the degrees of safety awareness vary throughout majors and grades. It is imperative to enhance the safety education system, and institutions should expand the range of safety courses and consider the use of diverse teaching approaches.

In reaction to the growing number of accidents occurring in university laboratories, it is imperative to proactively and consistently prioritise the enhancement of laboratory safety education and training in order to heighten the safety consciousness of laboratory personnel. While certain Chinese universities have adopted elements of the EHS system, such as mandatory laboratory safety education and training courses, to enhance safety management efficiency[5], this approach has not been widely implemented in local colleges and universities due to inadequate management capabilities. Thus, there is a common reliance on laboratory safety management systems, safety inspections, safety emergency mechanisms, and similar measures in these institutions. To establish a fundamental safety culture and create a secure environment, it is imperative to thoroughly prioritise the implementation of targeted practical instructional courses. By incorporating essential safety guidelines into laboratory experiments, university students can develop a heightened consciousness of safety, building a solid foundation for promoting a culture and environment of safety. Previous research[12] has emphasized the key role of teachers and laboratory managers in enhancing students' laboratory safety awareness. A survey conducted by Sonawane *et al* [13] highlighted the significant impact of institutional policies and educators in shaping students' views and practices regarding chemical safety. Corresponding to this point of view, Savolainen *et al* [14] argued that if the leadership of an organization fundamentally values and prioritizes safety, then it can establish a safety education environment with satisfactory safety standards.

Nowadays, there is a strong emphasis on researching and improving safety standards in higher education institutions to increase the safety awareness of college students in laboratories. Amidst the current era of substantial academic transformations, there is an increasingly pressing need to enhance safety education. In response to the pressing need, our research addressed laboratory safety education reform in an experimental teaching classroom. We achieved this by repeatedly testing the fundamental laboratory safety knowledge of sophomore students, who have already passed the entrance examination, using the content from the school's laboratory safety entrance examination question bank. Additionally, our survey research was conducted within the context of biochemistry laboratory teaching. We enhanced the experimental classroom teaching technique by implementing an effective dual-teacher guiding model. This model involves one experimental teacher who is responsible for teaching theoretical knowledge on biochemistry laboratory operations and integrating safety training related to experimental operations. Additionally, an assistant experimental teacher uses various methods to provide multi-level safety education and enhance students' safety training throughout the experimental teaching course. This strategy prioritised the consistency of safety education, minimised the time required for training in experimental operation skills, and fostered students' autonomous learning of laboratory safety knowledge through progressive guidance, gradually enhancing their safety awareness and practical abilities.

The key component of this educational reform is the implementation of the dual-teacher guided model, which integrates safety education training into the instruction and evaluation of experimental courses. The favourable impact on the safety attitudes and behaviours of college students has resulted from the increased awareness of laboratory safety facilitated by the seamless integration of the teaching reform model. Furthermore, the successful execution of this educational reform initiative not only has educational value, but also offers opportunities to enhance and reinforce safety management plans and practices in teaching laboratories. This highlights the need for ongoing innovation in safety education training. Our research offers an objective reference for fostering safety consciousness among college students in experimental teaching classrooms in different fields. The created model is rapid, efficient, and enduring, making it suitable for adoption in a number of local colleges.

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2. Methodology

2.1. The Study Area and Sample Size

The study was conducted at Hangzhou Normal University (HZNU), in Zhejiang Province, China in 2022. HZNU is a normal university, cultivating outstanding teachers as one of its important goals, and in recent years it has been striving to develop into a high-level comprehensive university. It's crucial to note that HZNU adheres to stringent laboratory safety and security protocols. Departments such as chemistry, biology, medicine, radiation, machinery, special equipment, and isotopes are mandated to adhere to safety measures. As part of this regulation, all stakeholders—including undergraduates, graduates, faculty, and foreign trainees—are obligated to undertake a laboratory safety access test. Only upon successful completion are they granted a safety access card, a requisite for laboratory entry. Any individual without this card is explicitly denied access to the labs.

All the students in this study have the safety access card.Our sample encompassed 183 sophomore students, distributed as follows: 126 students across three biological science classes; 9 students from a single ecology class; 48 students from a science education class, specifically designed for teacher training, affiliated with the College of Physics.

2.2. Study Method, Data Collection and Analysis

In the experimental teaching classroom, the teacher taught the potential safety risks in experimental operations according to the current course content. The experimental teaching assistant used the following methods to implement specific safety educational measures.

2.2.1. Pre-Experimental Questionnaire

Before the experimental courses, a survey based on the general repository of laboratory safety information for colleges and universities in Zhejiang Province was conducted. This quiz covered a wide range of topics, including medical biology, chemistry, firefighting, electrical safety, and specialised equipment, among others. Relevant safety concerns connected to the biochemical laboratory environment, including fire safety, equipment safety, and biochemistry, were obtained from this large database. A total of 25 questions were posed to assess the existing safety knowledge of students who had previously obtained access to laboratory safety.

2.2.2. Rapid In-Class Safety Assessment

An expedited in-class safety knowledge evaluation was developed as part of the comprehensive experiment module called "Determination of Nitrogen Content by the Micro Kjeldahl Method." This was implemented to assess the effectiveness of safety instruction in the classroom in developing students' awareness of safety. This concise evaluation, consisting of three inquiries, was created to be finished within a three-minute timeframe, highlighting crucial safety principles for that particular laboratory session.

2.2.3. Interactive Safety Engagement

A competitive event called "Laboratory Safety Competition: Picture Identification" was organised to stimulate student interest and engagement. The inquiries were designed to specifically highlight common mistakes related to biochemical laboratory safety measures. The efficacy of this instructional approach was assessed quantitatively by monitoring student engagement and their level of accuracy in these safety competitions.

2.2.4. End-of-Course Safety Evaluation

To conclude the course, an evaluation was created, which mirrored the experimental preparation procedure. This assessment covered several aspects such as preparing reagents, using equipment, managing waste, and other related factors. The purpose of this assessment was to assess the level of safety information acquired by students after completing their biochemical lab training.

In addition to the conventional approach, many advanced procedures were implemented with the goal of enhancing students' proficiency in laboratory safety and strengthening their awareness of safety.

2.2.5. Safety educational Video learning

We selected outstanding entries from laboratory safety education video competitions run by peer organisations. The chosen movies were later included into the curriculum to be shown in all classes,

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providing visual and contextual understanding of safety procedures.

2.2.6. Promotion of Online Safety Courses

We thoroughly examined and carefully selected exceptional laboratory safety courses offered on the China University MOOCs website. These courses, which demonstrate exemplary methods and current guidelines, were then suggested to all class cohorts, guaranteeing that students have the opportunity to get cutting-edge safety instruction.

2.2.7. National Virtual Simulation Experimental Safety Platform

We provided students with access to a national virtual simulation experimental safety platform to support their strong interest in laboratory safety. This programme provides an immersive virtual environment that accurately simulates real-world circumstances, allowing students to practise safety measures and improve their preparation.

Upon completion of the course, a feedback questionnaire was given to students to evaluate the influence of these initiatives on student awareness. Additionally, it aimed to determine the effectiveness of various pedagogical tools, such as test questions, illustrative images, videos, and MOOCs, in enhancing students' understanding of laboratory safety.

3. Results and Discussion

By integrating safety education and training directly into laboratory teaching classrooms and establishing a seamless module for acquiring and implementing safety information, students' comprehension and capacity to comply to laboratory safety requirements were enhanced. The better understanding and cognitive grasp of laboratory safety knowledge proved to be especially advantageous for students with aspirations of pursuing higher education at the graduate level or embarking on a career in a research setting.

Figure 1 displayed the reform plan for this experimental instruction course. Various safety education and training approaches were incorporated into the traditional experimental teaching classroom, under the leadership of two teachers. These innovative teaching techniques closely aligned with the advancement of contemporary information technology and digital instruction. They aimed to foster and reinforce students' awareness of safety from many angles and viewpoints. The implementation of this teaching reform involved incorporating a safety education module into the experimental teaching classroom, resulting in a straightforward and efficient approach to quickly disseminate laboratory safety instruction.

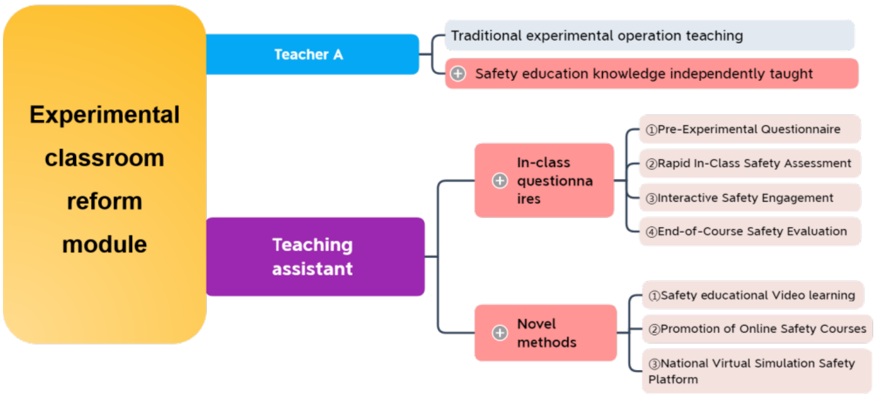

Figure 1: Experimental classroom reform module

3.1. Pre-Experimental Questionnaire

A total of 140 valid feedback responses were obtained. An in-depth analysis found full involvement from the biological science class, little involvement with only eight responses from the science education class, and a single missed response from the ecology class. Upon evaluating the feedback volume from each cohort, a clear and noticeable pattern emerged: students from the School of Life and Environmental

ISSN 2522-6398 Vol. 7, Issue 5: 24-30, DOI: 10.25236/FER.2024.070504

Sciences displayed a heightened level of concern over laboratory safety. Students from the School of Physics displayed lukewarm attitudes towards safety standards, highlighting the urgent requirement for more comprehensive safety education among this group. After carefully examining the responses, it was determined that the accuracy percentages for fire safety, equipment safety, and biochemistry were 39%, 49%, and 64% respectively. These statistics illustrate a common trend among sophomores: a limited to moderate understanding of laboratory safety standards. It is important to mention that, while all participants had passed the required laboratory safety entrance exam during their first year, its impact seems to be mostly theoretical. The practical memory of safety knowledge diminishes when not consistently reinforced in hands-on environments. The decrease in information retention is worrying, particularly considering the intensive hands-on coursework that these students are expected to participate in during their second year, which increases the risk of safety vulnerabilities.

3.2. Rapid In-Class Safety Assessment

During this session, students were presented with three specific questions. The purpose of these queries was to evaluate their proficiency in particular tasks: heating tubes, using the Kjeldahl micro quantitative distillation device, and operating a centrifuge correctly. Out of the 147 feedback entries received, only 68 accurately identified all of the mistakes. The majority of mistakes were associated with the balancing of the centrifuge. The result underscored a common deficiency among students: a restricted understanding of accurate and comprehensive equipment operation procedures.

3.3. Interactive Safety Engagement

The task resulted in 120 valid replies, with the majority of students demonstrating proficiency in identifying inappropriate laboratory practices. These activities included handling reagents without gloves, not following proper clothing guidelines, and preparing reagents while being distracted by using mobile phones. The findings demonstrated that the implementation of the dual-teacher leadership model, along with the corresponding routine safety activities, enhanced students' comprehension of safety operations. Nevertheless, there was still potential for further expansion. Although their comprehension had increased, it was not yet comprehensive, highlighting the necessity for more rigorous and ongoing safety education activities.

3.4. End-of-Course Safety Evaluation

A total of 123 valid feedback entries were examined.The analytical findings were promising, since most of the questions achieved an accuracy rate of over 90%. The positive response highlights the effectiveness of the dual-instructor concept and the ongoing method of reinforcing knowledge. However, when discussing the management of dangerous chemicals, particularly substances such as concentrated sulfuric acid, the rate of approval remains at a relatively low 63.4%. This difference can be attributed to various factors. A key aspect may be the organised environment of the experimental course. Typically, undergraduate students receive assistance from specialised staff members who prepare the required substances for their research. This design, although it guarantees a smooth progression of courses within specified time limits, unintentionally prevents undergraduates from gaining practical experience in handling volatile chemicals. Moreover, when undergraduate students engage in complex scientific research projects and competitions, the acquisition, use, and preservation of hazardous substances are mostly handled by graduate students. As a result of this situation, undergraduate students face limited opportunities to fully understand and effectively handle dangerous compounds. Therefore, the task of promoting or increasing understanding of safety aspects related to dangerous substances continues to be a difficult challenge.

The results of a sequence of activities, closely connected to the advancement of an experimental course, revealed a consistent pattern: the abstract principles of laboratory safety were regularly applied to practical experimental procedures. Through continuous exchange of knowledge, students demonstrated improved readiness by prioritising safety precautions while starting laboratory work and strictly following standardised experimental methods, significantly reducing potential safety risks. In contrast, the reference cohort, lacking immersion training, demonstrated inferior experimental techniques and occasionally exhibited careless behaviour, therefore increasing the likelihood of unintentional laboratory accidents. A study conducted by Rodrigues *et al* [15] indicated that interactive instructional tactics had a significant influence on students' risk perceptions and their intended safety-focused behaviours. Meanwhile, the expositive and demonstrative tactics effectively enhanced awareness and

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commitment to safety. Therefore, standard programmes may consider utilising this information, customising instruction through adaptable and diverse forms to achieve the best educational results.

3.5. Other Evaluations

This study selected laboratory safety videos from peer institutions and laboratory safety courses from the China MOOC platform, taking into account the process safety education implementation outlined by Mkpat *et al*.[16] and the safety learning requirements relevant to students' future professional paths. These tools were provided to students as supplementary learning materials, enhancing their hands-on involvement with the subject matter.

Following this initiative, an evaluative questionnaire was distributed. Out of the 104 thoroughly evaluated feedback forms, the pedagogical preferences of the students were clearly identified: 44% preferred concise video tutorials, 36.5% showed a preference for image-based error correction, and the remaining group leaned towards MOOC-based learning methods. Regarding concrete results arising from this educational innovation, a promising 78.8% of participants reported a significant increase in their awareness of laboratory safety. Moreover, a significant 90.3% emphasized their strong belief in the utmost significance of cultivating a thorough understanding of laboratory safety. The key point here is that in today's information-saturated world, students need to have a comprehensive understanding of laboratory safety measures that align with their real-life experiences. However, this fundamental understanding may not fully prepare individuals to effectively handle unexpected dangerous situations.

Surprisingly students proposed a variety of methods to enhance awareness of laboratory safety. Their suggestions ranged from giving specialized safety lectures that included relevant case studies to systematically sharing laboratory safety information through methods such as using images to identify errors, creating video tutorials, composing safety-focused songs, and conducting evaluations through questionnaires. Moreover, there was a noticeable tendency towards the establishment of compulsory safety courses and the arrangement of competitions focused on safety expertise. In addition, students clearly demonstrated a strong desire to not only increase their awareness of laboratory safety, but also to effectively apply this theoretical knowledge in actual situations. This feedback implies that the existing safety education and training may require a more thorough examination. It is imperative to develop programme that acknowledge the shared need and distinct variations between teaching and research laboratories. An implicit request is being made for the creation of effective implementation frameworks that are customized to acknowledge the common characteristics and distinct features of both teaching and research laboratories.

4. Conclusion

To the best of our knowledge, there are no dedicated safety offices concerned with undergraduates safety Safety education and training courses at HZNU. We believe that this is the first Teaching Reform Project conducted concerning laboratory safety awareness at this university. College students, as crucial recipients of process safety education[16], should incorporate cutting-edge safety education strategies to improve the safety skills of future professionals. This study assessed the laboratory safety awareness of university students who had obtained laboratory access permits. The results indicated that students have a basic understanding of fire safety, but their knowledge of safety in professional laboratories is lacking. Additionally, it was demonstrated that students exhibited deficiencies in their proficiency with high-temperature, high-pressure, and high-speed instruments and equipment. This includes their inadequate understanding of how to properly utilise high-speed centrifuges. These shortcomings can be attributed to the students' limited exposure to operating in such challenging circumstances.

One disadvantage of this study is that the theory and laboratory courses are instructed by various teachers, resulting in uneven levels of safety education and training content across different teachers. Furthermore, a constraint exists in the form of incomplete responses from certain students in the survey.

It is recommended to use the safety education mode of in-class teaching and assessment to enhance the laboratory safety awareness of college students. In particular, it can be combined with popular video teaching, high-quality course learning, virtual simulation safety platforms, and other novel ways to broaden students' safety perspective. Through such enriching and easy-to-operate classroom reform methods, it can effectively enhance the laboratory safety awareness of teachers and students, establish a fundamental safety culture and facilitate practical outcomes in managing safety at regional higher education institutions.

ISSN 2522-6398 Vol. 7, Issue 5: 24-30, DOI: 10.25236/FER.2024.070504

Acknowledgement

This work was supported by the Teaching Reform Project of Zhejiang Province (grant number jg20220495), Teaching Reform Project of Hangzhou Normal University [2022].

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