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Research Trends in Laboratory Safety within Science Education: A Bibliometric Analysis (2016–2025)

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ABSTRACT

This study aims to analyze research trends on laboratory safety in science education using a bibliometric approach. Although laboratory safety has become increasingly important in educational settings, comprehensive bibliometric studies focusing specifically on science education remain limited. Data were retrieved from the Scopus database covering the period 2016–2025, resulting in 1,089 documents analyzed using Biblioshiny. Several bibliometric indicators were employed, including publication trends, co-authorship analysis, country and affiliation productivity, keyword co-occurrence networks, and thematic mapping. The findings indicate a steady growth in publications, reflecting increasing global interest in laboratory safety within educational contexts. The analysis reveals that research is dominated by a few leading countries, particularly the United States and China, while authorship patterns show strong collaboration but no single dominant contributor. Furthermore, keyword and thematic analyses demonstrate that the field is primarily driven by human-centered and empirical studies, with emerging trends toward technology-based approaches such as machine learning. However, pedagogical aspects, including laboratory instruction and hands-on learning, remain less integrated within the core research structure. These findings provide important implications for future research, science education policy, and curriculum development, particularly in strengthening the integration of laboratory safety practices within science teaching and learning.

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INTRODUCTION

Science education is closely related to practical activities conducted in laboratories. Laboratory work is one of the key components that plays an important role in supporting the success of the science teaching and learning process (Shana & Abulibdeh, 2020). A laboratory is a place for observation, experimentation, testing, and training in the development of knowledge and technology. Laboratories are expected to support the learning process in order to achieve optimal learning outcomes, thereby improving students' academic performance. However, in reality, many schools have not yet utilized laboratories effectively as learning media. To ensure that science laboratories in schools can function optimally, Asmarany et al. (2024) argued that a well-planned, implemented, and evaluated laboratory management system is required, involving all stakeholders responsible for laboratory operations. Science laboratories are managed to meet users' needs in accordance with their intended functions and purposes. Therefore, the effective utilization of laboratories as supporting facilities in the teaching and learning process must be accompanied by proper and structured management (Ruth et al., 2026; Widiyanto, 2022).

According to Cavas and Koç (2022), laboratory safety management has therefore become an essential aspect of science education. The presence of chemical substances, laboratory equipment, and experimental procedures increases the likelihood of accidents if proper safety measures are not implemented. In educational settings, safety issues are often associated with inadequate safety knowledge, lack of supervision, insufficient training, and limited availability of safety facilities (C.-M. Chen et al., 2024; Kim & Chung, 2023). These challenges highlight the importance of integrating safety awareness and risk management into science learning environments. In recent years, research on laboratory safety in educational contexts has grown significantly (Cavas & Koç, 2022; Li & She, 2026), covering topics such as safety culture, risk assessment, safety management, and students' safety behavior. This growing body of literature reflects increasing global awareness of the importance of maintaining safe laboratory environments in schools and universities. However, despite the expanding number of publications, there is still a lack of comprehensive studies that systematically map and analyze the development, trends, and research patterns in this field.

Undertaking a bibliometric analysis provides an appropriate approach for evaluating the contribution of scientific publications to the advancement of knowledge within a particular research field (Hidaayatullaah & Suprapto, 2022; Prahani et al., 2024). Bibliometric indicators, such as research areas, source titles, publication output, authorship patterns, country and institutional distribution, citation analysis, and keyword co-occurrence, are widely used to identify research trends and intellectual structures (Nisa et al., 2024). Although several previous bibliometric studies have examined laboratory safety or science education separately, comprehensive analyses specifically focusing on laboratory safety within the context of science education remain limited. Moreover, previous studies have generally emphasized publication performance without extensively exploring conceptual structures, thematic evolution, and emerging research trends through advanced visualization analysis. Notably, the present study selected the period 2016–2025 because it represents the

most recent decade of research development, allowing the identification of contemporary trends, emerging topics, and the rapid growth of technology-integrated approaches in science education research. Therefore, the present study aims to analyze research trends related to laboratory safety in science education using a bibliometric approach. In addition, this study seeks to explore the global distribution of research contributions, including the most productive countries, institutions, and authors in this field. Furthermore, this study also examines collaboration patterns and emerging research themes using visualization tools provided by Biblioshiny.

Accordingly, this study focuses on the research trends of laboratory safety in science education by addressing the following research questions:

1. What are the main characteristics and development trends of publications on laboratory safety in science education?
2. Who are the most productive authors, countries, and institutions contributing to research on laboratory safety in science education?
3. What are the keyword trends and how are they visualized in mapping the research on laboratory safety in science education?

METHOD

According to H. E. Chen et al. (2023), the selection process in bibliometric studies consists of three main stages: search, screening, and synthesis. In this study, bibliographic data were retrieved from the Scopus database because, according to Tuyet et al. (2024), it provides comprehensive coverage of high-quality peer-reviewed publications and reliable citation data widely used in bibliometric research. The initial search was conducted using the following query: TITLE-ABS-KEY (("laboratory safety" OR "lab safety" OR "chemical safety" OR "laboratory risk" OR "safety management") AND ("education" OR "teaching" OR "learning" OR "students" OR "school" OR "university") AND ("science education" OR "physics education" OR "chemistry education" OR "biology education" OR "STEM education")). To refine the dataset, several inclusion criteria were applied. The time span was limited to publications between 2016 and 2025 to capture recent developments in the field. The document type was restricted to journal articles to ensure the inclusion of peer-reviewed and high-quality scientific outputs. Furthermore, only articles published in English were considered to maintain consistency and facilitate data analysis. After applying these criteria, the final dataset consisted of 1089 documents, which were deemed suitable for bibliometric analysis. The overall article selection process is presented in Figure 1.

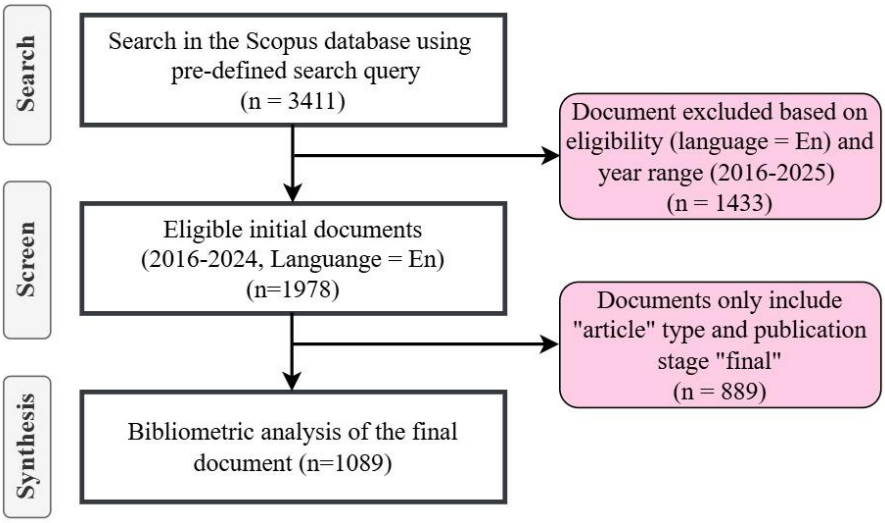

Figure 1. Article selection process

The selected records were exported in comma-separated values (.csv) format, including essential bibliographic information such as authors, affiliations, titles, abstracts, keywords, source titles, and countries. The dataset was then analyzed using Biblioshiny, a web-based interface of the Bibliometrix package (Aria & Cuccurullo, 2017). This tool enables comprehensive bibliometric analysis and visualization of scientific publications. Moreover, it ensures the application of standardized bibliometric indicators and visualization techniques, thereby enhancing the reliability and validity of the findings, as well as enabling comparison with previous bibliometric studies in related fields. A quantitative descriptive approach was employed to analyze the bibliometric data in accordance with the research questions (Rizki, 2022; Suprapto et al., 2025). The analysis included (1) publication trends over time, (2) identification of the most productive authors, journals, countries, and institutions, (3) co-authorship analysis to examine collaboration patterns, and (4) keyword co-occurrence analysis to identify research hotspots and emerging themes. These analyses provide insights into the intellectual structure and development of research on laboratory safety in science education.

Table 1. Search parameters and dataset characteristics used in the bibliometric analysis

Aspect	Description
Database	Scopus
Search Field	TITLE-ABS-KEY
Search Query	(laboratory OR lab) AND (safety OR safe OR sandbox) AND (education OR teaching OR learning OR student OR school OR university OR curriculum) AND (science OR physics OR chemistry OR biology OR "science education" OR STEM)
Time Span	2016–2025
Document Type	Journal Articles
Language	English
Total Initial Records	3411

Total Final Documents	1089
Analysis Tool	Biblioshiny (Bibliometrix R-package)
Bibliometric Indicators	Publication trends, co-authorship, country productivity, affiliation analysis, keyword co-occurrence, thematic mapping
Inclusion Criteria	English-language journal articles related to laboratory safety in science education
Exclusion Criteria	Conference papers, book chapters, non-English documents, irrelevant laboratory safety studies

RESULTS AND DISCUSSION

Main Characteristics and Development Trends (RQ1)

The bibliometric dataset on laboratory safety in science education covers the period 2016–2025, comprising 1,089 documents from 585 sources, with an annual growth rate of 12.35%, indicating increasing research interest (see Table 2). The average document age is 4.51 years, with a mean of 14.28 citations per document and a total of 104,383 references, reflecting a moderately influential and well-established knowledge base. In terms of content, 8,451 Keywords Plus and 3,232 author keywords highlight the diversity of research themes. A total of 6,398 authors contributed to the publications, with only 96 single-authored documents, while the average of 6.05 co-authors per document suggests strong collaborative patterns. However, international collaboration remains relatively limited at 18.46%, indicating potential for greater global research integration in this field.

Table 2. Descriptive statistics of publications on laboratory safety in science education (2016–2025)

Description	Results
MAIN INFORMATION ABOUT DATA	
Timespan	2016:2025
Sources (Journals, Books, etc)	585
Documents	1089
Annual Growth Rate %	12.35
Document Average Age	4.51
Average citations per doc	14.28
References	104383
DOCUMENT CONTENTS	
Keywords Plus (ID)	8451
Author's Keywords (DE)	3232
AUTHORS	
Authors	6398
Authors of single-authored docs	86
AUTHORS COLLABORATION	
Single-authored docs	96
Co-Authors per Doc	6.05
International co-authorships %	18.46

The annual scientific production of publications on laboratory safety in science education shows an overall increasing trend from 2016 to 2025 (see Figure 2). The number of articles grew modestly from 61 in 2016 to 74 in 2019, followed by a notable surge in 2020 (108 articles) and a peak in 2021 (168 articles). Although a slight decline occurred in 2022 (110 articles), the publication output recovered in subsequent years, reaching 142 articles in 2023 and 135 in 2024, before attaining the highest number in 2025 with 174 articles. This fluctuation, combined with a strong upward trajectory, indicates a growing and sustained research interest in laboratory safety within science education, particularly in recent years.

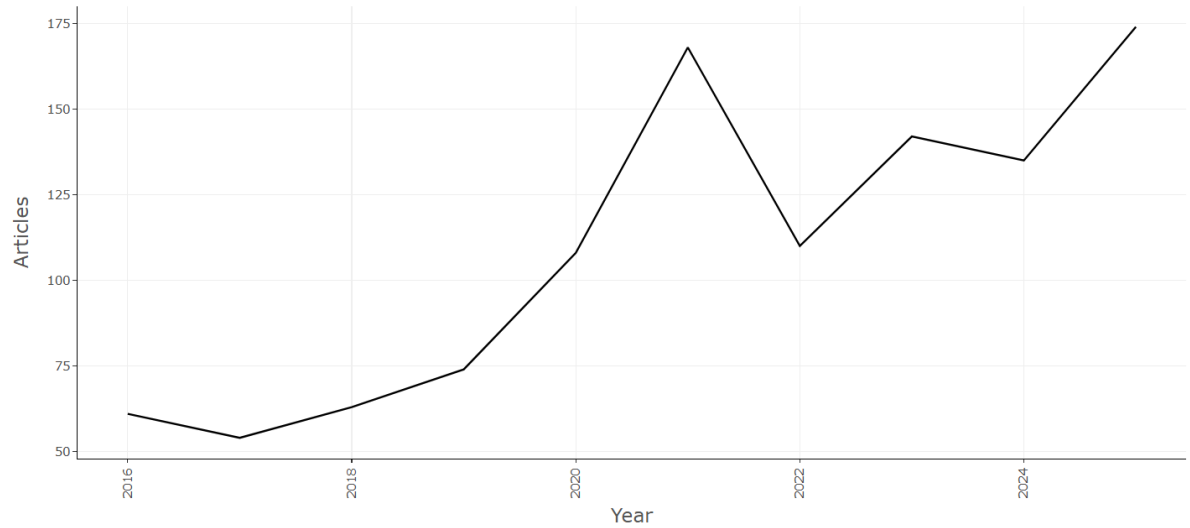

Figure 2. Annual scientific production of publications on laboratory safety in science education

The trend of average citations per year in publications on laboratory safety in science education demonstrates a fluctuating pattern over the 2016–2025 period, as seen Figure 3. In the early years, citation impact was relatively moderate, with values declining from 2.79 in 2016 to 1.65 in 2017, before gradually increasing and reaching a peak in 2021 at 3.54 citations per year. This peak indicates a period where published studies gained higher academic attention and influence. However, after 2021, a declining trend is observed, with citation averages dropping to 2.08 in 2022 and further decreasing to 1.20 in 2025. This decline is likely influenced by the shorter citable years for more recent publications, which have had less time to accumulate citations. Overall, while earlier publications tend to show higher citation impact due to longer exposure, the data suggest that the field experienced its highest citation influence around 2019–2021, followed by a gradual normalization in more recent years.

Most Productive Authors, Countries, and Institutions (RQ2)

The analysis of the most productive authors in laboratory safety research within science education reveals a relatively dispersed authorship pattern (see Figure 4). The highest number of publications is shared by Jin Xinglong and Wang Xiaoyan, each contributing six

articles, indicating their prominent role in this research area. However, when considering fractionalized contributions, Sigmann Samuella B. demonstrates the highest contribution (3.33), suggesting a stronger individual involvement across publications. Other notable contributors include Love Tyler S., Faulconer Emily K., and Goode Scott R., each with consistent contributions and relatively high fractionalized values, reflecting active participation in collaborative research. The absence of a single dominant author and the relatively low number of publications per author indicate that this research area is still evolving and not yet concentrated among a few leading scholars. This pattern suggests that laboratory safety in science education is characterized by a collaborative and interdisciplinary research environment, where knowledge production is shared across multiple contributors rather than centralized within a specific research group.

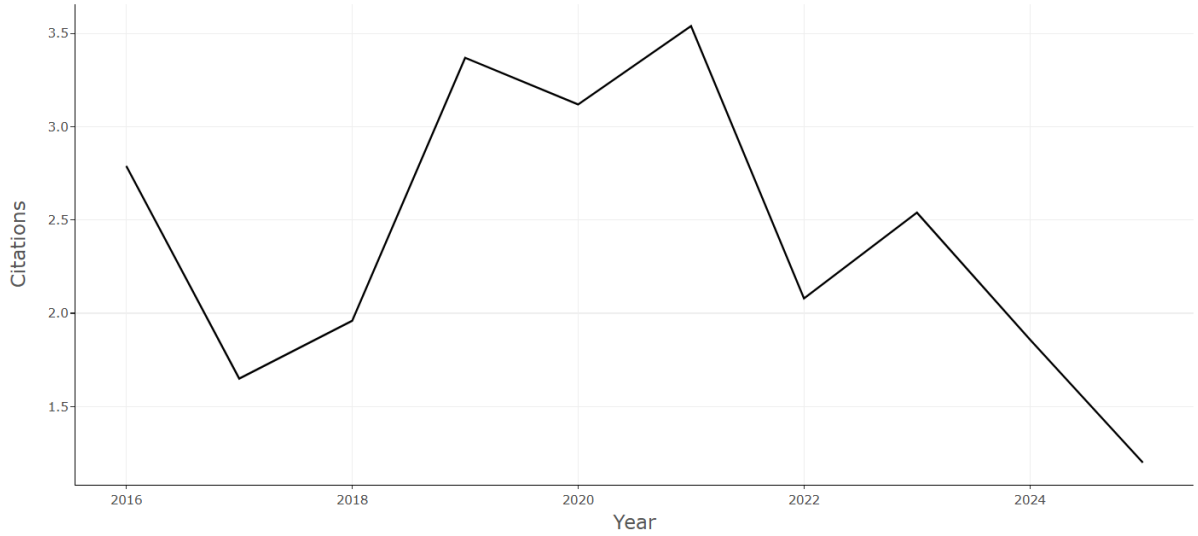

Figure 3. Annual average citations per article in publications on laboratory safety in science education

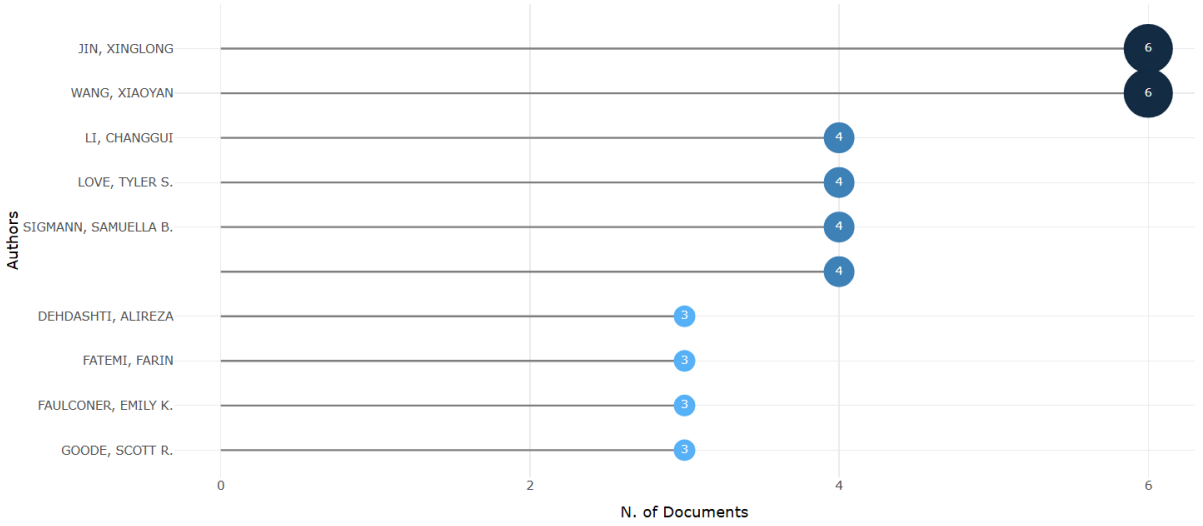

Figure 4. Most productive authors in laboratory safety research within science education based on total publications

The analysis of author production over time shows varying patterns of productivity and citation impact among leading contributors in laboratory safety within science education, as presented in Figure 5. Authors such as Jin Xinglong and Wang Xiaoyan demonstrate consistent publication output between 2021 and 2023, indicating sustained research activity in recent years. In contrast, Li Changgui exhibits a notably high citation impact, particularly in 2021, suggesting the influence of a highly cited publication. Similarly, Faulconer Emily K. shows a strong citation performance in earlier years, although later contributions received less attention. Meanwhile, Dehdashti Alireza and Fatemi Farin display increasing citation impact in recent years, indicating growing visibility of their work. These patterns suggest that while several authors maintain consistent productivity, citation influence is uneven and often concentrated in specific periods or publications.

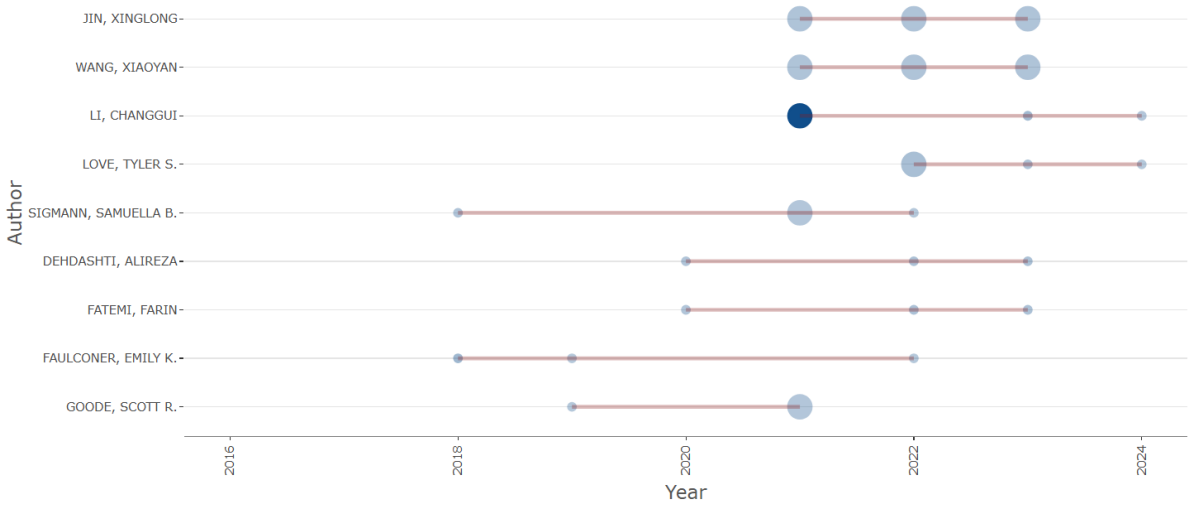

Figure 5. Temporal distribution of authors' publications

Figure 6 shows the analysis of the top 10 most productive countries in laboratory safety research within science education, revealing a clear dominance of a few leading nations. The United States ranks first with 1,848 publications, followed by China (934), indicating a substantial gap between the two leading contributors and other countries. This pattern reflects the strong research capacity of these countries, particularly in terms of funding availability, advanced laboratory infrastructure, and well-established academic institutions. Countries such as Iran (273), the United Kingdom (250), and Germany (227) also demonstrate significant contributions, highlighting their active engagement in both science education and safety-related research. Meanwhile, India, Italy, Australia, Spain, and Canada show moderate but consistent productivity, suggesting a broad yet uneven global participation in this field. This distribution can be largely explained by structural differences in national research ecosystems. Leading countries typically invest heavily in research and development, enabling access to modern laboratory facilities, safety equipment, and well-trained personnel, all of which are essential for conducting and publishing research on laboratory safety. In addition, strong institutional support and international collaboration networks in these countries facilitate higher research output and visibility. The emphasis on

STEM education policies also plays a crucial role, as countries with well-developed science education systems are more likely to prioritize laboratory-based learning and, consequently, safety practices within educational settings. Conversely, countries with more limited resources may face challenges in both implementing laboratory safety standards and producing related research, which contributes to the observed disparity in publication output.

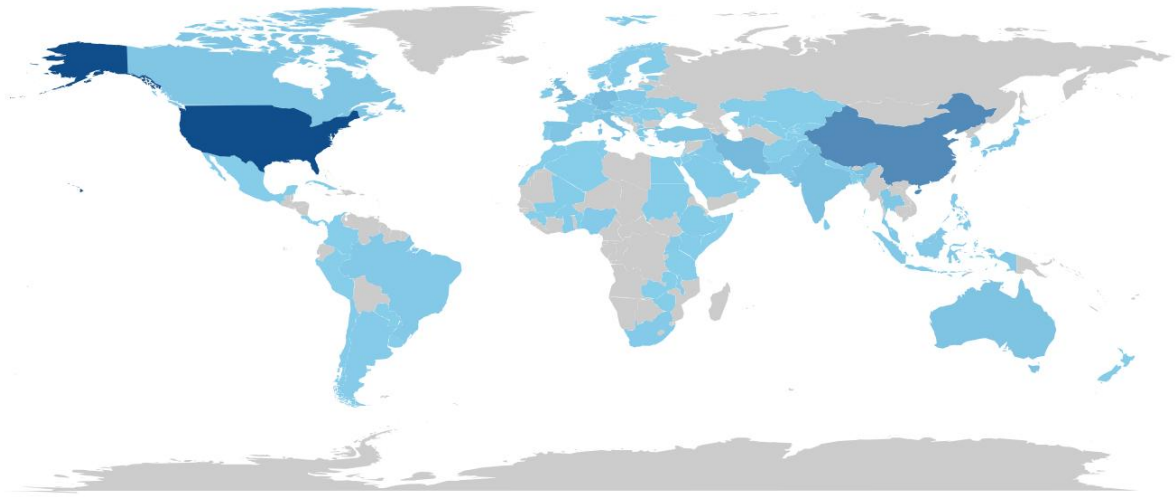

Figure 6. Most productive countries in the field

The analysis of the most productive affiliations highlights the significant contribution of research-intensive institutions, particularly those with strong backgrounds in medical and scientific research (Figure 7). Shiraz University of Medical Sciences ranks first with 66 publications, followed by University of California (50) and Icahn School of Medicine at Mount Sinai (42). Other notable institutions include Shahid Beheshti University of Medical Sciences (41), University of Minnesota (37), Xiamen University (36), and Shanghai Jiao Tong University (32). This distribution indicates that institutions with strong medical and health science orientations play a dominant role in laboratory safety research, likely due to their intensive use of laboratories and strict safety regulations. This pattern also implies that laboratory safety research in science education is often influenced by practices and standards originating from medical and experimental science environments, where safety considerations are critically emphasized.

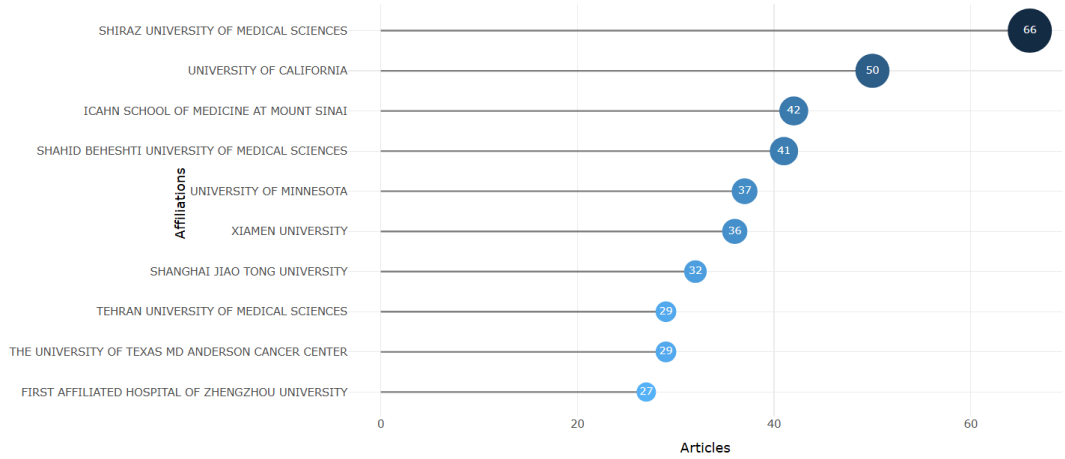

Figure 7. Most productive institutions in the field

Keyword Trends and Conceptual Structure (RQ3)

The analysis of the most frequent words reveals that general indexing terms such as "human" (368), "article" (332), and "humans" (271) dominate the dataset, followed by demographic-related terms including "female" (181), "male" (174), and "adult" (154), as depicted in Figure 8. In addition, methodological and educational terms such as "controlled study" (151), "laboratory instruction" (118), "procedures" (88), and "hands-on learning/manipulatives" (86) indicate the practical and instructional orientation of research in this field. These findings suggest that laboratory safety research in science education is strongly associated with experimental contexts involving human participants and emphasizes structured laboratory practices and experiential learning approaches.

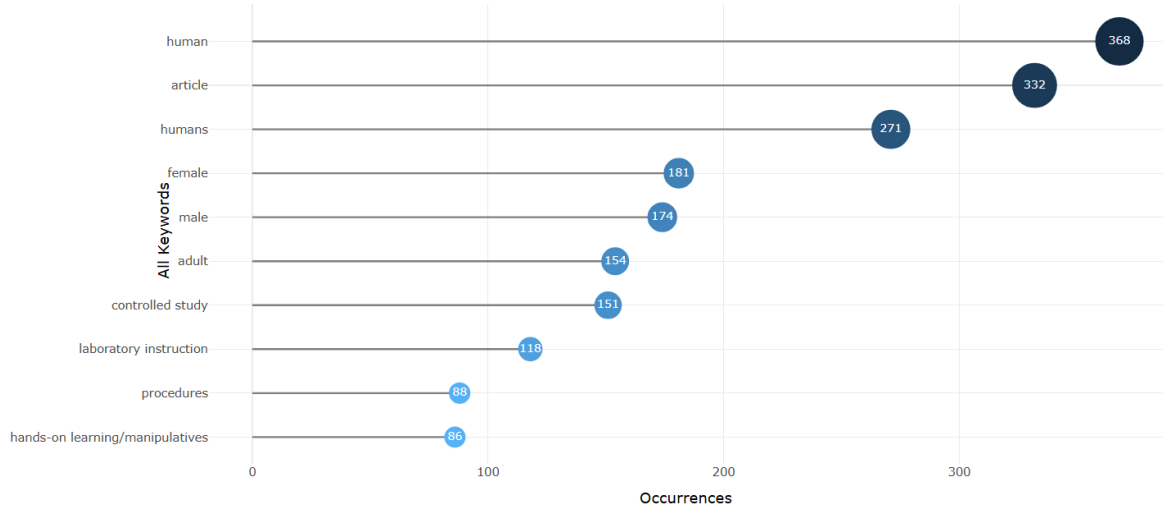

Figure 8. Most frequent word analysis

Figure 9 presents the analysis of word dynamics over time that shows a consistent and significant increase in the occurrence of key terms related to laboratory safety in science education. General indexing terms such as "human," "article," and "humans" exhibit a steady upward trend, reflecting the overall growth in publication output. Similarly, demographic-related terms including "female," "male," and "adult" increase progressively, indicating a

sustained focus on human participants in research studies. Methodological and instructional terms such as “controlled study,” “laboratory instruction,” “procedures,” and “hands-on learning/manipulatives” also demonstrate notable growth, particularly after 2020, suggesting an increasing emphasis on structured experimental design and practical learning approaches in recent years. These trends indicate that the development of research in this field is closely aligned with the expansion of empirical, practice-oriented, and participant-based studies over time. Researchers may increasingly prioritize evidence-based approaches and real laboratory contexts to improve safety practices and learning effectiveness in science education.

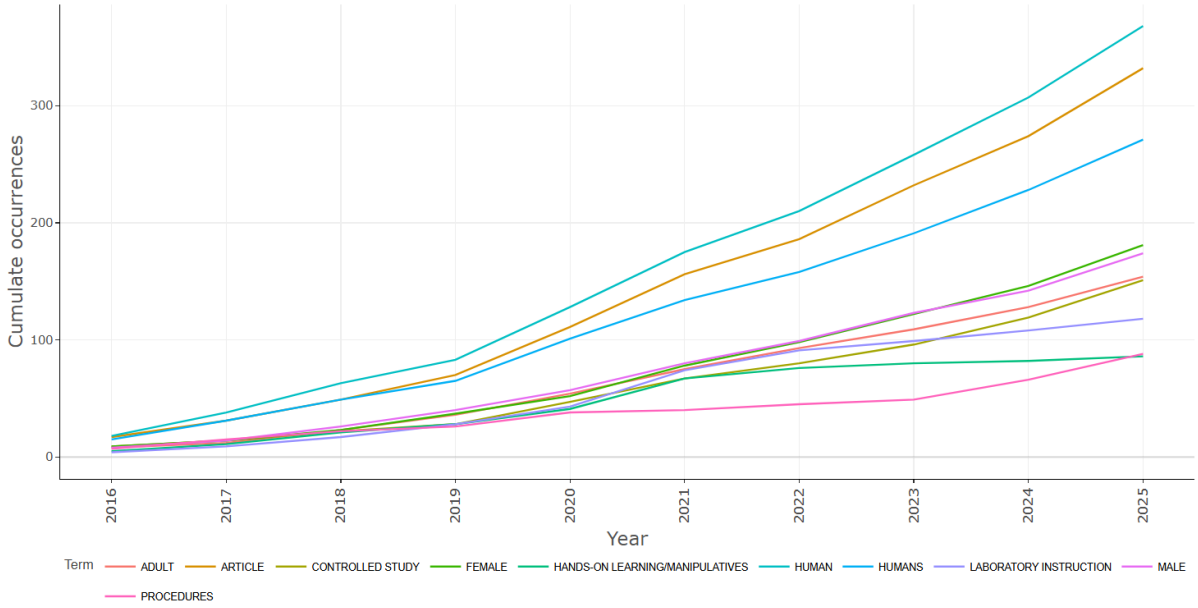

Figure 9. Word dynamics from 2016 to 2025

As illustrated in Figure 10, the analysis of trend topics reveals the temporal evolution of research themes in laboratory safety within science education. Early research (2016–2018) was primarily characterized by foundational themes such as “standards,” “ethics,” and “statistical analysis,” indicating an initial focus on establishing methodological rigor and regulatory frameworks. Between 2018 and 2021, the focus shifted toward disciplinary and practice-oriented topics, including “green chemistry,” “laboratory instruction,” “hands-on learning,” and “upper-division undergraduate,” reflecting the integration of safety practices into teaching and experimental activities. In more recent years (2022–2025), emerging topics such as “machine learning,” “learning systems,” “food safety,” and “diagnosis” have gained prominence, suggesting a transition toward more advanced, technology-driven, and interdisciplinary research directions. This shift indicates that the field is evolving from foundational and instructional concerns toward more complex and data-driven approaches, where digital technologies and applied contexts play an increasing role. The emergence of topics such as machine learning suggests that researchers are beginning to explore innovative methods for enhancing laboratory safety, including predictive analysis and intelligent systems. Furthermore, the appearance of applied domains such as food safety and drug

therapy implies a growing connection between science education and real-world laboratory applications, highlighting the expanding scope and relevance of this research field.

The keyword co-occurrence network reveals a multi-cluster conceptual structure in laboratory safety research within science education (see Figure 11). Cluster 1 is dominated by instructional and pedagogical terms such as "laboratory instruction," "hands-on learning," and "undergraduate," indicating a strong focus on teaching practices and student engagement. Cluster 2 represents the core scientific and experimental context, with highly central nodes such as "human" and "humans," which exhibit the highest betweenness and PageRank values, suggesting their pivotal role in connecting multiple research themes. Meanwhile, Cluster 3 is characterized by clinical and demographic-related terms such as "female," "male," "adult," and "controlled study," reflecting the influence of health and experimental research contexts, while standalone nodes like "safety" and "curriculum" act as important bridging concepts across clusters. This structure indicates that laboratory safety research in science education is inherently interdisciplinary, integrating educational practices with experimental and clinical research perspectives. The dominance of "human" as a central node suggests that much of the research is grounded in participant-based studies and real-world laboratory contexts. Additionally, the presence of distinct yet interconnected clusters implies that future research may increasingly focus on bridging pedagogical approaches with advanced scientific and clinical safety practices to create more comprehensive laboratory safety frameworks.

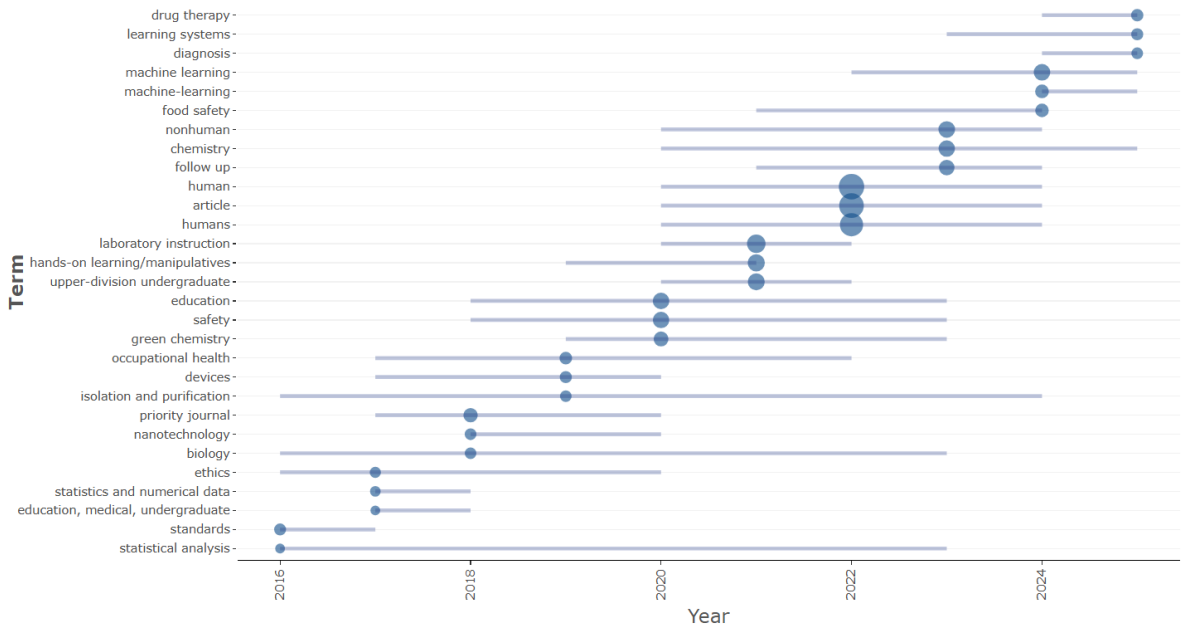

Figure 10. Trend topics from 2016 to 2025

The thematic map reveals the distribution of research themes based on their centrality and density in laboratory safety within science education (Figure 12). The motor themes quadrant is dominated by "human," "article," and "humans," indicating that participant-based and empirically grounded studies play a central and well-developed role in the field, while

"procedures," "nonhuman," and "education" appear as basic themes that are important but less developed. In contrast, topics such as "laboratory instruction," "hands-on learning," and "upper-division undergraduate" are positioned as niche themes, suggesting specialized but less interconnected research areas, whereas "curriculum," "physical chemistry," and "quantitative analysis" fall into emerging or declining themes with low centrality and development. These patterns suggest that the field is currently driven by empirical human-centered research, while pedagogical and curriculum-related topics remain less integrated, indicating opportunities for future studies to strengthen connections between instructional practices and core laboratory safety research.

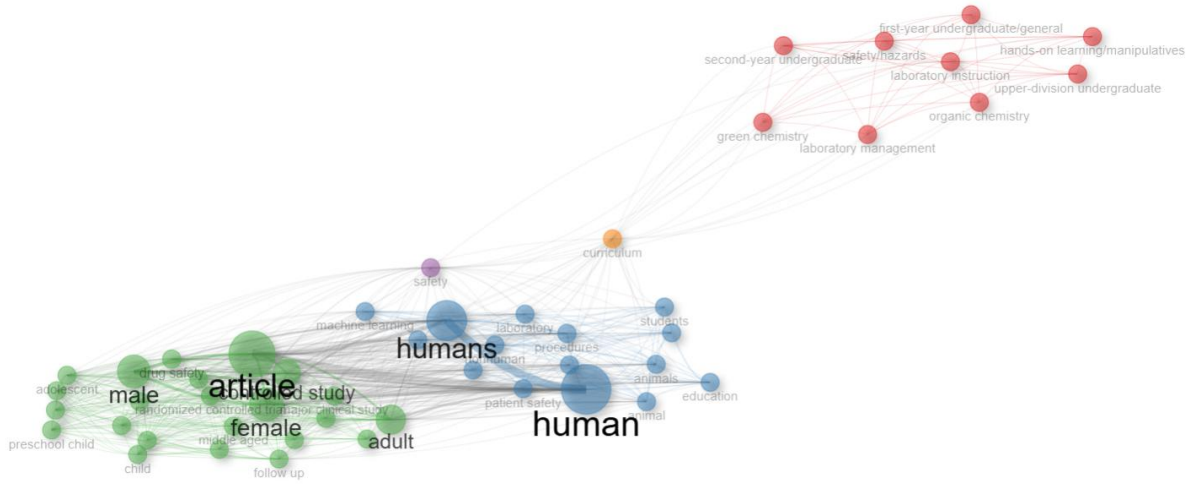

Figure 11. Co-occurrence network analysis

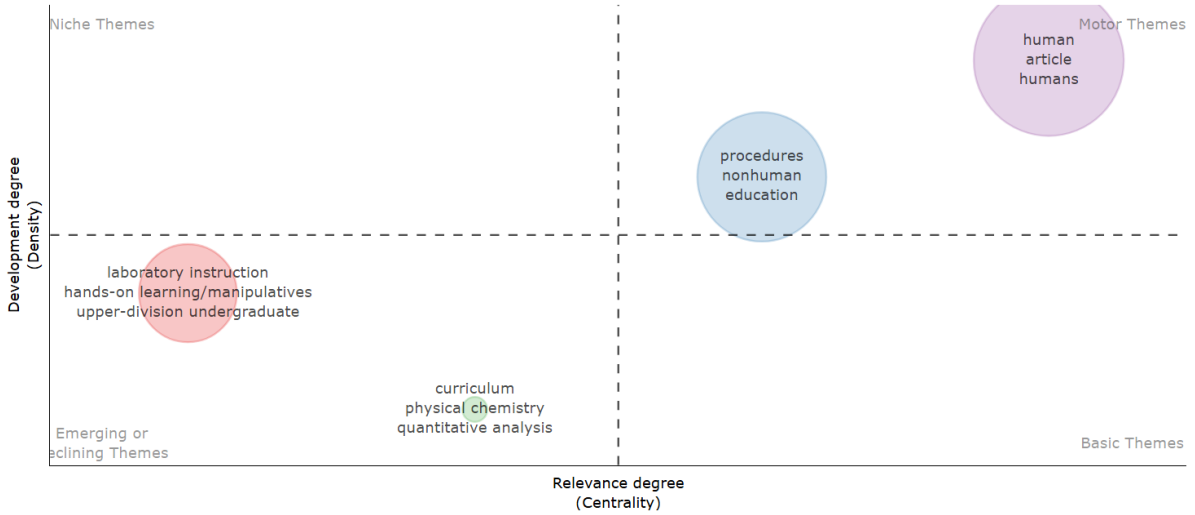

Figure 12. Thematic map

This analysis reveals that research on laboratory safety in science education has experienced substantial growth and diversification, reflecting increasing global attention to safety practices in educational laboratory settings. The descriptive and network analyses show that the field is characterized by collaborative authorship patterns and a

multidisciplinary structure that integrates educational, scientific, and clinical perspectives. Furthermore, the dominance of human-centered and empirical research highlights the strong emphasis on participant-based studies and real laboratory contexts in shaping current knowledge. At the same time, the thematic and keyword analyses reveal that while research is advancing toward more complex and technology-driven approaches, certain pedagogical aspects remain less central within the overall research structure. Wang et al. (2025) asserted that this may be because laboratory safety research is still largely driven by scientific, medical, and technical disciplines that prioritize procedural compliance, risk management, and experimental outcomes rather than instructional innovation and curriculum integration. As a result, laboratory safety is often treated as a supporting operational concern rather than as a core component of science pedagogy and learning design. These findings are consistent with previous bibliometric studies, such as Yang et al. (2019), which also identified laboratory safety as a multidisciplinary yet still developing research field with limited international collaboration and uneven global contributions.

The similarity in patterns, including the dominance of certain countries and the relatively fragmented research community, reinforces the notion that this field has not yet reached full maturity. Research emphasizes that effective safety education requires active learning and constructivist experiences. However, when bibliometric analyses aggregate data across all laboratory safety publications (which include industrial, clinical, and academic settings), the specific, nuanced pedagogical frameworks often become overshadowed by the sheer volume of empirical, technology-driven, and risk-assessment studies (He et al., 2025). Furthermore, studies confirm that science laboratory safety is no longer a isolated educational concern but a multidisciplinary field integrating expertise from scientific research, clinical/medical safety standards, and educational pedagogy (Feng & Kirkley, 2020). This trend also reflects broader developments in digital science education and laboratory modernization, where increasing adoption of intelligent systems, virtual laboratories, data analytics, and technology-enhanced learning environments has shifted research attention toward technical innovation and operational efficiency (Wu & Chen, 2025). Consequently, instructional and curriculum-oriented discussions may receive comparatively less emphasis despite their critical role in fostering long-term laboratory safety awareness and practices among students.

A comparison with previous bibliometric studies in science education further supports these findings. Bibliometric analyses of science education research have reported that recent trends are increasingly dominated by STEM education, technology integration, interdisciplinary learning, and digital transformation in educational contexts (Tosun, 2024). Similarly, studies on virtual laboratories in STEM-based science learning found that research has progressively shifted toward technology-supported laboratory environments, interactive learning systems, and science process skills development (He et al., 2025). These patterns align with the present study, which identified the growing prominence of technology-driven and empirical research themes. Moreover, the findings of Yang et al. (2019) also emphasized that laboratory safety research remains fragmented and highly multidisciplinary, integrating scientific, educational, and safety-management perspectives. These similarities indicate that

laboratory safety research in science education is evolving in parallel with broader transformations in digital science education and laboratory modernization.

These findings imply that there is a necessary transition from viewing safety as a list of rules to be memorized (compliance) to treating it as a core scientific competency (literacy). Because research currently prioritizes technical and operational risk management, students often learn safety as an imposed external constraint rather than an intrinsic element of experimental design (Abu-Siniyeh & Al-Shehri, 2021; Muhlis et al., 2025). This suggests that curricula need to be redesigned to teach students why specific safety protocols exist, empowering them to conduct independent risk assessments rather than simply following static manuals. Future research should place greater emphasis on integrating laboratory safety principles with instructional design and teaching practices in science education. There is also a need to develop more innovative and technology-supported approaches, such as data-driven safety monitoring and intelligent learning systems, to enhance both safety and learning outcomes (Rizki et al., 2021). Additionally, strengthening international collaboration and interdisciplinary research could further advance the development of comprehensive and globally relevant laboratory safety frameworks.

CONCLUSION

This study provides a comprehensive bibliometric overview of research on laboratory safety in science education from 2016 to 2025. The findings reveal a steady increase in publication output, indicating growing scholarly interest in this field, along with a collaborative yet dispersed authorship pattern without a single dominant contributor. The analysis also identifies the most productive authors, countries, and institutions, with a clear concentration of research output in a few leading nations, particularly the United States and China, reflecting disparities in global research capacity. Furthermore, keyword and network analyses highlight that the field is dominated by human-centered and empirical research, with emerging trends toward technology-driven approaches such as machine learning, while pedagogical aspects remain less central. These findings comprehensively demonstrate that laboratory safety research in science education is an evolving and multidisciplinary field, with opportunities for further integration between educational practices and safety research. Practically, the findings suggest that curriculum developers should integrate laboratory safety more explicitly into science curricula through inquiry-based activities, risk assessment training, and technology-supported laboratory learning. In addition, science educators are encouraged to adopt more student-centered and experiential safety instruction, including the use of virtual laboratories, simulations, and reflective safety practices to strengthen students' long-term safety awareness and scientific competencies.

Despite providing a comprehensive overview of research trends on laboratory safety in science education, this study has several limitations. First, the analysis was limited to documents indexed in the Scopus database and published in English, which may exclude relevant studies from other databases or non-English publications. Second, the bibliometric approach primarily focuses on publication metadata and network patterns, meaning that the quality and depth of individual studies were not examined in detail. Future research could

expand the database coverage by including sources such as Web of Science or Dimensions and conduct comparative analyses across databases. In addition, further studies are recommended to explore the effectiveness of specific pedagogical approaches, digital laboratory technologies, and safety-oriented instructional models in improving students' laboratory competencies and safety behaviors.

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