Mapping teaching and learning challenges in laboratory environments: A scoping review

Mapeamento das dificuldades de ensino e aprendizagem em ambientes laboratoriais: Uma revisão de escopo

Mapeo de las dificultades de enseñanza y aprendizaje en entornos laboratoriales: Una revisión de alcance

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Abstract
Objective: To map the difficulties faced by educators and students in science laboratories within the teaching-learning process. Method: A scoping review following the JBI protocol, utilizing Boolean operators (AND/OR) across nine databases. Inclusion criteria: studies published between 2020–2025 focusing on challenges in natural/health science laboratories. Exclusion criteria: studies involving virtual laboratories, animal models, or non-empirical research. Results: Twelve studies revealed interconnected challenges in infrastructure, insufficient educator training, inadequate management, and lack of biosafety protocols. Discussion: Material precariousness undermines experimental work, perpetuating a theory-practice disconnect. Deficits in educator training and excessive workload hinder the overcoming of these barriers, creating a cycle of pedagogical insufficiency. Conclusion: The difficulties are systemic and require integrated interventions in infrastructure, educator training, and management policies to establish functional laboratory environments.
Keywords: Teaching; Laboratories; Scoping review.

Resumo
Objetivo: mapear as dificuldades enfrentadas por docentes e discentes em laboratórios de ciências no processo de ensino-aprendizagem. Método: Revisão de escopo conforme protocolo JBI, utilizando operadores booleanos (AND/OR) em nove bases de dados. Critérios de inclusão: estudos publicados entre 2020-2025 focados em desafios em laboratórios de ciências naturais/saúde. Exclusão: estudos com laboratórios virtuais, modelos animais ou não empíricos. Resultados: Doze estudos evidenciaram desafios interconectados em infraestrutura, formação docente insuficiente e gestão inadequada, além da falta de biossegurança. Discussão: A precariedade material inviabiliza a experimentação, perpetuando um ensino desconectado da prática. A formação docente deficitária e a sobrecarga educacional impedem a superação dessas barreiras, criando um ciclo de insuficiência pedagógica. Conclusão: As dificuldades são sistêmicas e requerem intervenções integradas em infraestrutura, formação docente e políticas de gestão para efetivar ambientes laboratoriais funcionais.
Palavras-chave: Ensino; Laboratórios; Revisão de escopo.

Resumen
Objetivo: Mapear las dificultades enfrentadas por docentes y discentes en laboratorios de ciencias dentro del proceso de enseñanza-aprendizaje. Método: Revisión de alcance siguiendo el protocolo JBI, utilizando operadores booleanos

(AND/OR) en nueve bases de datos. Criterios de inclusión: estudios publicados entre 2020-2025 enfocados en desafíos en laboratorios de ciencias naturales/salud. Criterios de exclusión: estudios con laboratorios virtuales, modelos animales o investigaciones no empíricas. Resultados: Doce estudios revelaron desafíos interconectados en infraestructura, formación docente insuficiente, gestión inadecuada y falta de protocolos de bioseguridad. Discusión: La precariedad material inviabiliza la experimentación, perpetuando una desconexión teoría-práctica. La formación docente deficitaria y la sobrecarga educativa impiden superar estas barreras, creando un ciclo de insuficiencia pedagógica. Conclusión: Las dificultades son sistémicas y requieren intervenciones integradas en infraestructura, formación docente y políticas de gestión para establecer ambientes laboratoriales funcionales.
Palabras clave: Enseñanza; Laboratorios; Revisión de alcance.

1. Introduction

Science laboratories represent fundamental pillars of experimental education, enabling the articulation between theory and practice, which is essential for scientific training (Prasiska et al., 2024). Well-planned and structured laboratory activities enhance meaningful learning, the development of technical skills, and critical thinking (Haedar et al., 2024). However, their effectiveness depends directly on adequate conditions of infrastructure, resources, and methodologies—factors that are often neglected in diverse educational contexts (Rahmoon et al., 2024).

Laboratories, such as those in chemistry, biology, and pharmacy, are important spaces for the development of practical skills and the consolidation of theoretical knowledge (Shahzadi, 2023). In the educational context, laboratories are considered physical spaces that differ significantly from conventional classrooms. These environments are equipped with a variety of specialized materials and equipment, including precision instruments, specific glassware, and chemical reagents. The use of these resources requires care and safety measures, which are essential for the proper development of practical activities (Arsene et al., 2020). Moreover, laboratories provide a favorable environment for experimentation and the practical application of theoretical knowledge, allowing students to experience and better understand the concepts studied (Hendratno et al., 2023). The presence of suitable equipment and specific materials in a controlled educational environment not only enriches learning but also prepares students for future professional practices in their respective fields of study. In addition, the practical experience gained in a well-structured laboratory promotes a deeper understanding of theoretical concepts, facilitating the application of knowledge in real and complex situations. This practical approach not only benefits students but also provides educators with the necessary tools to improve their teaching practices, creating a positive dynamic in the teaching-learning process (Shiraz et al., 2021).

It is essential to understand that laboratory sessions should not be limited solely to the manipulation of reagents or objects in the laboratory environment. They should be conceived as integrative moments between theory and practice, in which scientific knowledge is contextualized based on its historical, philosophical, and epistemological foundations (Rashid & Subramaniam, 2024). Understanding the processes that led to the construction of knowledge, as well as the theoretical conceptions underlying the practice to be carried out, is essential for students to develop a critical and reflective view of laboratory practices. In this way, experimental activity transcends its technical-operational character, assuming a broader and more meaningful formative role in the educational process.

Nevertheless, educators and students face challenges that compromise the use of these environments, ranging from a lack of material resources to pedagogical and infrastructural issues (Abas et al., 2020). Biosafety, waste disposal, and the preservation of natural resources are also associated with the difficulties encountered in laboratory sessions (Safdar et al., 2023). Furthermore, teacher training for the effective use of these spaces is often insufficient, resulting in poorly utilized, poorly planned practical classes with inadequate use of materials (Vasconcelos & Rocha, 2025). Understanding these difficulties is essential to propose improvements that make laboratory activities more accessible, safer, and aligned with educational needs. Based on this premise, one may ask: What are the main difficulties faced by educators and students in science laboratories within the teaching-learning context?

In addition, by systematically identifying and categorizing these difficulties, this study lays the groundwork for the future development of an educational application specifically designed to address the mapped challenges. The analysis will guide the functionalities of the digital tool more effectively, ensuring that it meets the real needs of these educational environments. Thus, this review will serve as the foundation for a technological solution aimed at transforming obstacles into opportunities for improving laboratory teaching.

The objective of this study is to map the difficulties faced by educators and students in science laboratories within the teaching-learning process.

2. Methodology

This study is based on a qualitative approach, complemented by descriptive quantitative analysis of data extracted from the selected articles, following scientific research methodology guidelines (Pereira et al., 2018). It adopts the scoping review methodology due to its capacity to map key concepts, identify gaps in the literature, and synthesize evidence on emerging or complex themes (Arksey & O'Malley, 2005; Peters et al., 2024). To ensure transparency and methodological rigor, the study follows the PRISMA-ScR checklist (Tricco et al., 2018) and is registered on the Open Science Framework (OSF) under the DOI: https://osf.io/v7rg8/. Prior registration of the protocol ensures traceability and reduces reporting bias, in line with recommendations for evidence synthesis research.

This approach is relevant for investigating difficulties in science laboratories, a field characterized by a wide dispersion of qualitative studies, experience reports, and isolated analyses, but lacking comprehensive syntheses. Following the Joanna Briggs Institute (JBI) protocol (Peters et al., 2024), the review was conducted in five stages: (1) defining the research question; (2) systematic search in databases and portals; (3) study selection based on inclusion and exclusion criteria; (4) extraction and organization of data into predefined categories; (5) critical synthesis of results. The JBI methodology, widely recognized in scoping reviews (Munn et al., 2018), ensures rigor by allowing the inclusion of different types of evidence (qualitative, quantitative, and practical reports), which is essential to capture the multidimensional nature of the problem. Additionally, the approach facilitates the identification of patterns, which are fundamental for proposing contextualized solutions, such as the development of the planned educational application.

To define the scope of the investigation, the PCC mnemonic strategy — Participants, Concept, Context — was applied, a widely recognized method for formulating research questions in scoping reviews (Peters et al., 2024). In this study, the participants (P) are science educators and students; the concept (C) encompasses operational, pedagogical, and structural difficulties encountered in physical laboratories; and the context (C) is restricted to in-person teaching within primary, secondary, and higher education institutions. This structured framework supported the formulation of the central research question: *"What are the main difficulties faced by educators and students in science laboratories within the teaching-learning context?"* The PCC approach thus ensures clarity and precision in defining the review's boundaries, minimizing thematic dispersion.

To ensure both comprehensiveness and relevance, systematic selection criteria were defined. The review included primary studies employing quantitative, qualitative, or mixed-methods designs, as well as secondary studies of various types (systematic, scoping, integrative, and narrative reviews, among others), provided they were available in full and in any language. Regarding the timeframe, only studies published between 2020 and 2025 were considered to ensure the inclusion of up-to-date evidence. The target population comprised educators and students who encountered challenges in science laboratories. The central concepts addressed operational difficulties, including lack of supplies, maintenance issues, pedagogical approaches, and structural or safety-related problems. Concerning the context, the review focused exclusively on natural and health science laboratories associated with educational institutions.

Studies on virtual laboratory technologies, research not focused on the challenges of educators and students, and those using animal or *in vitro* models were excluded. Incomplete materials or inconclusive data, as well as non-empirical publications such as editorials, were also discarded. This screening ensured that only relevant evidence for mapping teaching laboratory difficulties was analyzed.

The search strategy was constructed using the Boolean operators AND and OR in both Portuguese and English. Combinations of descriptors and keywords were derived from multiple controlled vocabularies, including Health Sciences Descriptors (DeCS), Medical Subject Headings (MeSH), the ERIC Thesaurus, and Emtree Terms (Embase), to ensure both the breadth and precision of the search.

The search was carried out between February 5 and 27, 2025, in the following databases and portals: Biblioteca Virtual em Saúde (BVS), Scientific Electronic Library Online (SciELO), United States National Library of Medicine/Medical Literature Analysis and Retrieval System Online (PubMed/MEDLINE), Excerpta Medica dataBASE (Embase Elsevier), Education Resources Information Center (ERIC), Web of Science (Clarivate Analytics), Scopus, Google Scholar, and the CAPES Theses & Dissertations Catalog. References of all articles and reports identified in the search were also examined to identify additional relevant studies. The search strategy is described in Table 1.

Table 1 - Search strategy in databases and gray literature. Botucatu, SP, Brazil, 2025.

Databases	**Search Strategy**
Biblioteca Virtual de Saúde (BVS)	(ensino) AND (laboratórios) AND (química) AND fulltext:("1" OR "1") AND instance:"regional" (Ensino) AND (Laboratórios) AND (Química) with filter: texto completo
SciELO	(Ensino) AND (Laboratórios) AND (Química) (Ensino) AND (Laboratórios) AND (Química)
PubMed/Medline	(((Teaching) AND (Laboratories)) AND (Chemistry)) AND (Learning Disabilities)
Embase (Elsevier)	('teaching'/exp OR 'teaching') AND ('laboratory'/exp OR 'laboratory') AND ('chemistry'/exp OR 'chemistry') AND ('challenge'/exp OR 'challenge')
Web of Science (Clarivate Analytics)	Teaching (All Fields) AND Laboratories (All Fields) AND Chemistry (All Fields) AND Learning Disabilities (All Fields)
ERIC	"Student Teaching" AND Laboratories AND "Learning Disabilities"
Scopus	(ALL(teaching) AND ALL(laboratories) AND ALL(chemistry)
Gray Literature	
Google Scholar	Ensino AND Laboratório AND Dificuldades com filtros: ordenar por datas
CAPES Theses & Dissertations Catalog	Ensino AND Laboratórios com filtros: 2020 a 2022; Dissertações e Teses (Acadêmico e Profissional); Grande área do conhecimento (ciências biológicas, saúde, exatas e da terra)

Source: Prepared by the Authors (2025).

The identified references were imported into Rayyan software, developed by the Qatar Computing Research Institute (QCRI), for the archiving, organization, and screening of articles. The PRISMA-ScR guideline (Tricco et al., 2018) was adopted to structure the study selection process and to present the results of article inclusion, following its four stages: identification, screening, eligibility, and inclusion. After removing duplicates, study selection was performed independently by two reviewers, based on the information provided in the titles and abstracts. Articles that did not meet the inclusion criteria or failed to address the research question were excluded. In the subsequent phase, the full texts of the remaining articles were assessed to determine their final inclusion. Disagreements between reviewers were resolved through discussion, and when necessary, a third reviewer was consulted. All reasons for exclusion were quantified, documented, and justified in the scoping review. Upon completion of the selection phase, the reference lists of the included studies were analyzed using the snowballing technique, a literature search strategy that enhances the identification of relevant studies by exploring the citations of consolidated works to expand the search base (Pinheiro et al., 2024). References retrieved through this method that met the predefined inclusion criteria were incorporated, following the same selection principles established for this review.

Data extraction was conducted using an Excel spreadsheet developed by two independent and blinded reviewers, enabling a structured visualization of the information obtained from the selected studies and incorporating unique perspectives during the extraction process. The extraction strategy was defined and adapted in accordance with the JBI Manual for Evidence Synthesis, and included the following variables: authorship, year of publication, language, country of origin, study type, study objective, population and context, reported challenges, conclusions, recommendations, and study limitations. An integrated analytical approach was adopted to examine the extracted data, and any disagreements were resolved through consensus among the authors. For statistical analyses, the open-source software JASP (*Jeffreys's Amazing Statistics Program*), developed by the University of Amsterdam, was employed, providing a user-friendly interface for performing descriptive, inferential, and graphical analyses (Wagenmakers et al., 2023). Finally, the findings were interpreted in light of both national and international literature, allowing for a triangulation of relevant evidence to strengthen the discussion.

The presentation and interpretation of the extracted data were provided through figures, charts, and tables, structured in alignment with the objective and guiding research question of this review. A narrative synthesis accompanied the tabulated and/or graphical results to facilitate interpretation and to ensure compliance with the JBI recommendations for scoping reviews. It is important to note that the aim of this scoping review did not encompass the evaluation of methodological quality or the assessment of risk of bias in the included studies.

This study relied exclusively on secondary data obtained from scientific literature for the purposes of a literature review and, therefore, did not require evaluation by a Research Ethics Committee (Brazil, 2016). This research forms part of the broader project entitled *"Development of a Prototype Mobile Application for Didactic Support in Laboratory Environments."*

3. Results

We conducted searches in the main databases and subsequently in gray literature. The selection produced the following results: Biblioteca Virtual em Saúde (BVS) n=168, Scientific Electronic Library Online (SciELO) n=11, United States National Library of Medicine/Medical Literature Analysis and Retrieval System Online (PubMed/MEDLINE) n=17, Excerpta Medica dataBASE (Embase Elsevier) n=39, Education Resources Information Center (ERIC) n=1138, Web of Science (Clarivate Analytics) n=25, Scopus n=945, Google Scholar n=127, and CAPES Theses & Dissertations Catalog n=235. The search identified 2,343 articles in the databases and 362 in gray literature, totaling 2,705. Of these, 57 studies were excluded as duplicates, leaving 2,648 for title and abstract screening from both sources.

After the first analysis—title and abstract screening—2,597 studies were excluded, and 24 were selected for full-text reading. Of these, 9 met the selection criteria, were validated, and included. In a second selection step, we applied the snowballing technique using the references of previously selected studies, obtaining 419 studies through this process. After screening titles and abstracts, 410 were excluded, and 9 were selected for full-text reading. This resulted in 3 studies being added to the first stage. The final sample consisted of 12 articles (n1=9 + n2=3) for data extraction and synthesis, as shown in Table 2.

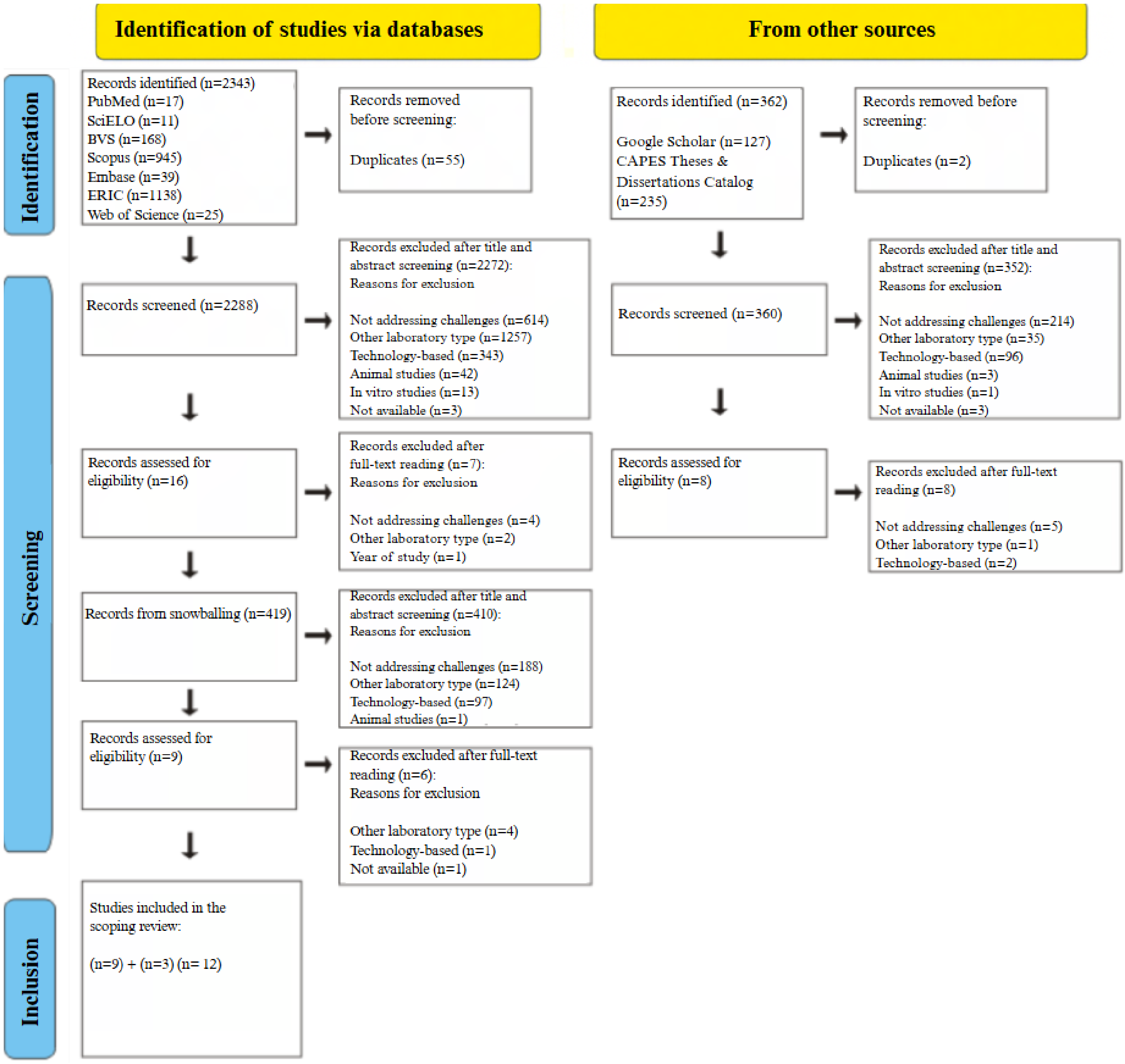
Table 2 – Articles identified through searches in databases and gray literature for selection.

Database	**Results of articles found**	**Articles previously selected**	**Final selected articles (E1)**	**Articles selected via snowballing**	**Articles previously selected**	**Final selected articles (E2)**
BVS	168	4	3	71	3	0
SciELO	11	2	0	0	0	0
PubMed / MEDLINE	17	1	0	0	0	0
Embase	39	0	0	0	0	0
ERIC	1138	7	6	348	6	3
Web of Science	25	0	0	0	0	0
Scopus	945	2	0	0	0	0
Gray Literature						
Google Scholar	127	7	0	0	0	0
CAPES Catalog	235	1	0	0	0	0
Total (both sources)	2705	24	**9 (n1)**	419	9	**3 (n2)**
Final total (n1+n2)	**12**					

Source: Prepared by the Authors (2025).

To increase understanding of the process, Flowchart 1 illustrates the entire selection analysis and the reasons for exclusion of the studies analyzed. Both sources of searches were included and distributed across the stages of: Identification, Screening, and Inclusion.

Figure 1 - Flowchart of the study selection process.



Source: Prepared by the Authors (2025).

Below, in Table 3, we present the primary characteristics of the selected studies, including the authors, country of origin, year of publication, the databases where they were found, titles, and type of study. Each study was assigned an ID (identifier), which will be maintained to facilitate citation in tables or subsequent mentions.

Table 3 – Primary characteristics of the analyzed studies.

ID	Author / Country	Year / Database	Title	Type of Study
01	Soyikwa & Boateng, África do Sul	2024, ERIC	Teaching physical sciences in South African rural high schools: Learner and teacher views about the challenges	Qualitative research
02	Byukusenge, et al., Ruanda	2023, ERIC	Difficult topics in the revised biology curriculum for advanced level secondary schools in Rwanda: teachers' perceptions of causes and remedies	Descriptive study with mixed approach
03	Abidoye, et al., Nigéria	2022, ERIC	Instructional resources for teaching biology in secondary schools in Moro, Kwara State–Nigeria	Descriptive research and statistical analysis
04	Albano & Delou, Brasil	2021, BVS	Principais dificuldades apontadas no ensino-aprendizagem de Química para o Ensino Médio: revisão sistemática	Systematic literature review
05	Ménardi & Trant,Canadá	2020, BVS	A review and critique of academic lab safety research	Narrative literature review
06	Munyemana, et al., Ruanda	2022, ERIC	Students' perceptions on the difficulty of biochemistry concepts covered in Rwandan secondary school biology curriculum	Exploratory mixed research
07	Ndjangala, et al., Namíbia	2021, ERIC	Teachers' views on challenges affecting learners' performance in natural science	Qualitative research
08	Giovanni, Brasil	2021, BVS	Controle de estoque e de banco de reagentes: estratégia para minimização de resíduos químicos em instituição de ensino e pesquisa	PhD Dissertation, cross-sectional study
09	Wang, et al., China	2022, ERIC	Challenges Encountered by Student Teachers in an Inquiry-Based Laboratory Process	Mixed-methods research
10	Silva, et al., Brasil	2021, Snowballing ERIC	Atividades práticas em espaços laboratoriais no ensino de Ciências e Biologia: relatos de uma experiência com estudantes dos anos finais da educação básica da Ilha de São Luís – MA	Experience report with action-research approach
11	Murcahyanto, et al., Indonésia	2023, Snowballing ERIC	Optimization of Management of Laboratory Facilities in the Process of Learning Science at High School	Descriptive quantitative research
12	Silva, et al., Brasil	2020, Snowballing ERIC	Relato de Experiência: Dificuldades Encontradas no Ensino de Química em uma Escola de Nível Médio no Município de Coari-AM	Experience report

Source: Prepared by the Authors (2025).

In Table 4, we outline the focus of the studies, substantiating the difficulties encountered and distinguishing them according to the perspective of the primary stakeholders involved in the challenges.

Table 4 – Detailed characteristics of the analyzed studies.

ID	Objective	Methodological Synthesis	Difficulties Faced	Stakeholders
01	Investigate the challenges faced by teachers and students in teaching physical sciences in rural South African schools, proposing strategies to improve education quality	Semi-structured interviews with 4 teachers and 12 students from four rural schools; thematic analysis according to Braun & Clarke (2006), based on self-study and constructivist theories	Absence of laboratories, lack of materials, exclusive use of textbooks, lack of internet and technological resources, impossibility of carrying out practical activities	Teachers and students
02	Identify the most difficult topics to teach in Rwanda's high school biology curriculum, understand the causes of these difficulties, and propose strategies to overcome them	Questionnaire applied to 67 high school biology teachers; descriptive statistical analysis and qualitative analysis of perceptions about difficulties and suggested improvements	Lack of laboratory equipment, absence of visual materials, impossibility of conducting practicals, and need for improvisation due to scarcity of resources	Teachers
03	Assess the availability and use of instructional resources for teaching biology in secondary schools in Moro, Kwara State, and investigate the influence of teacher qualifications and school type on their use	Questionnaire applied to 60 biology teachers from 18 schools; data analyzed by percentage, ANOVA, and t-test to verify relationships between variables	Absence of biology laboratories in more than 70% of schools; lack of essential equipment such as microscopes, human skeletons, test tubes, and dissection materials	Teachers
04	Identify, through a systematic review, the main difficulties faced by students and teachers in high school Chemistry teaching and learning in Brazil	Systematic review based on Kitchenham's (2004) protocol, with screening of 173 studies in national and international databases, resulting in 70 analyzed by thematic categories and subcategories	Lack of laboratories, reagents, equipment, maintenance, and technical support; lack of time and structure for practicals; overworked teachers without specific training for conducting experiments	Teachers and students
05	Critically evaluate the state of research on academic chemistry laboratory safety, identify methodological gaps, and propose directions for future investigations and institutional policies	Narrative and critical review of empirical studies, accident reports, perception surveys, and laboratory safety training practices, with multifactorial analysis of available data	Lack of systematized accident data; underreporting; lack of formal training; improper use of PPE; negligent institutional culture; resistance of teachers to implement safe practices	Teachers and students
06	Investigate high school students' perceptions of the difficulty of biochemistry concepts in Rwanda's biology curriculum and identify contributing factors	Questionnaires and group interviews with 195 final-year high school students in six schools; descriptive statistical analysis and qualitative categorization of responses	Lack of laboratory practicals, absence of resources such as videos and simulations, overly theoretical learning environment, hindering comprehension of concepts like photosynthesis and cellular respiration	Students
07	Investigate teachers' perceptions of the challenges affecting upper-primary students' performance in natural sciences in Omusati, Namibia	Face-to-face interviews with 7 natural science teachers from three schools; thematic analysis of responses to identify patterns and recurring challenges	Absence of laboratories and equipment; lack of experimental materials; neglect of practical activities, compromising students' performance in practical assessments	Teachers

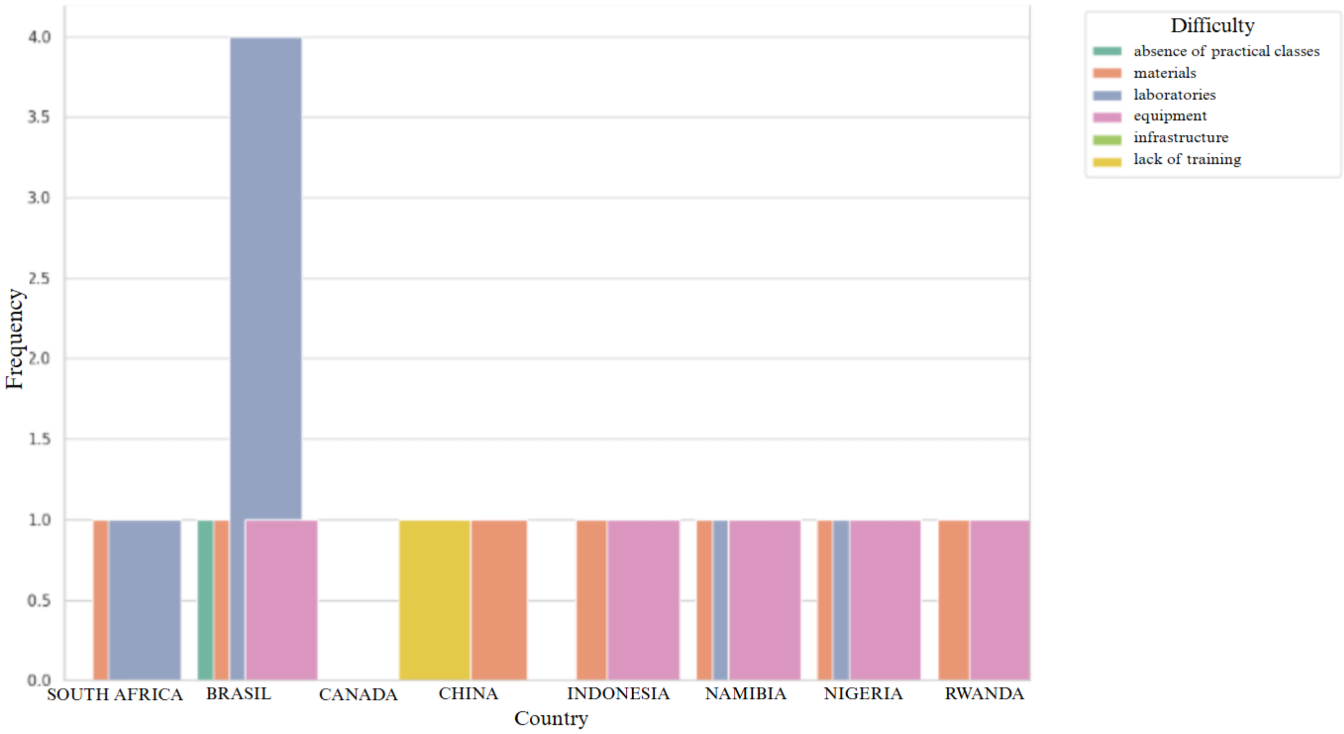
08	Study chemical waste management in laboratories at FMUSP, identifying and classifying waste, proposing strategies for reduction and control, aiming at occupational safety and sustainability	Cross-sectional study in seven laboratories at FMUSP and IMT (2017–2019), with inventory sheet analysis, questionnaire application, waste classification via GHS and ANTT, and identification of chemical incompatibilities using the EPA-600/2-80-076 method	Lack of professional chemists (75%), lack of training (63%), waste due to expiration (42.8 kg), 182 chemical incompatibility cases, inventory control failures, waste, and lack of communication between laboratories	Teachers and students
09	Investigate the challenges faced by preservice teachers in conducting inquiry-based chemistry labs and how these challenges affect their perceptions of process difficulty	26 preservice Chinese teachers participated. Data collection: structured questionnaire, semi-structured interviews, and reflective reports. Combined quantitative and qualitative analysis of challenges faced in inquiry-based labs	Main challenges: formulating inquiry questions, lack of prior knowledge, difficulty in searching and evaluating information, time and material limitations, difficulties in group collaboration and presenting results	Teachers
10	Investigate how elementary students perceive practical science and biology activities, bringing them closer to the LABWICK university lab and evaluating the impact of this experience on learning	Conducted in three stages: diagnosis in 12 schools, LABWICK lab visit with practices and lectures, and post-visit evaluation with questionnaires. 199 students in diagnosis and 226 in lab visits	Lack of school laboratories, absence of practical classes, scarcity of materials, unprepared teachers, and large classes hindering experimental methodologies in Science and Biology classes	Students
11	Analyze science laboratory management in secondary schools, identifying current conditions, implementation of practical activities, and challenges faced, proposing solutions to optimize lab use in science teaching	Descriptive quantitative study using questionnaires, observations, interviews, and document analysis in eight schools. Participants: 100 students, teachers, and lab assistants. Data analyzed with descriptive statistics and correlations	Lack of materials and equipment, absence of lab technicians, poor administration, teacher overload, lack of planning and supervision, student disinterest in practical reports undermining experiment effectiveness	Teachers and students
12	Report the main difficulties faced by teachers in high school Chemistry, such as lack of resources, laboratories, and student disinterest	35-hour supervised internship in a public high school in Coari-AM, with classroom observations and teaching practice, analyzing challenges faced by teachers and students	Absence of laboratories, lack of didactic resources, inadequate spaces, and student disinterest hindering Chemistry teaching and meaningful learning	Teachers and students

Source: Prepared by the Authors (2025).

4. Discussion

The literature review shows that precarious infrastructure constitutes a central obstacle to the teaching of science across diverse geographic contexts. In the Omusati region of Namibia, educators face shortages of basic teaching materials (Ndjangala et al., 2021), a situation that parallels Brazilian public schools, where the absence of adequate laboratories seriously compromises the development of experimental activities (Rolim, 2025), a scarcity also present in Nigerian schools (Abidoye et al., 2022). This material limitation creates a pedagogical scenario in which fundamental scientific concepts remain confined to the theoretical domain, hindering the construction of learning through experimentation and reducing relevance for students (Albano & Delou, 2021). The problem is compounded by the fact that even institutions with some infrastructure often face management and maintenance challenges (Murcahyanto et al., 2023).

Figure 2 - Graph of the main difficulties presented by the cited studies.



Source: Prepared by the authors, created with JASP software (2025).

Faced with these structural limitations, creative educational strategies emerge that redefine the concept of the scientific learning environment. In riverside communities of the Brazilian Amazon, educators transform everyday materials into teaching resources (Honório, 2024), creating bridges between formal scientific knowledge and local knowledge. These adaptations go beyond mere improvisation, representing alternative modes of scientific literacy that recognize scarcity as a generator of innovation (Zandvliet, 2023). Similar experiences have been documented in Mexico, where teachers developed laboratory equipment from recycled electronic components (Agarwal et al., 2022), demonstrating that material scarcity can catalyze unexpected forms of educational creativity (Nikoloudakis & Rangoussi, 2024).

Teacher preparation in science faces the dual challenge of articulating scientific foundations with competencies to operate under diverse material realities. While training institutions often prioritize idealized laboratory models, daily practice demands skills for transforming limitations into pedagogical opportunities. In Rwanda, educators report specific difficulties with molecular biology topics (Munyemana et al., 2022). In Brazil, where rural and peripheral schools face similar challenges, parallel solutions have emerged that transform unconventional spaces into environments for experimental learning: school cafeterias are adapted for DNA extraction using household materials (salt, detergent, and alcohol), courtyards are turned into ecology labs through soil analysis with homemade kits, and community science fairs encourage empirical investigation with local resources (Lira & Senna Junior, 2024). Although these strategies cannot fully replace conventional laboratory experimentation, they allow students to visualize abstract concepts through observable phenomena in their immediate environment, creating cognitive bridges between scientific knowledge and local knowledge (Fedosina, 2024).

These experiences reveal an ecology of pedagogical knowledge that operates beyond traditional models of science education (Pereira & Simões, 2023). In Indonesian schools, educators created experimental alternatives using local knowledge and recycled materials (A'yuni et al., 2024), integrating conceptual rigor with cultural relevance. In Mexican Indigenous communities, teachers developed approaches that combine scientific methodologies with traditional botanical classification systems (Bakirova, 2023), addressing both resource scarcity and conventional hierarchies of knowledge, suggesting that pedagogical excellence can manifest in diverse ways across cultural and material contexts. The management of resources for science education highlights contrasts between educational levels. While basic schools often lack minimal infrastructure (Camargo et al., 2024), higher education institutions face distinct challenges, such as inadequate management of chemical waste (Teixeira, 2020). The absence of institutional plans for handling hazardous materials reveals systemic flaws that compromise the safety and sustainability of experimental activities. Comparisons with international standards (Ménardi & Trant, 2020) raise red flags that overcoming these issues will require not only material investments but also profound transformations in institutional culture.

Students' perceptions provide valuable insights into the pedagogical dynamics that truly make a difference. In public schools in Minas Gerais, Brazil, students show a preference for practical approaches (Silva et al., 2024), which allow them to experience scientific phenomena more fully. This demand contrasts with the predominance of lecture-based teaching in most institutions studied (Ndjangala et al., 2021), revealing a disconnect between adopted methodologies and student expectations. Responses to the challenges of science teaching vary across sociocultural contexts. In Brazil, noteworthy initiatives include local partnerships between schools and universities, such as those developed in Maranhão (Silva et al., 2021), where universities make their laboratories available for activities with basic education students. Conversely, countries like Rwanda have explored the potential of digital technologies to compensate for material shortages (Byukusenge et al., 2023), developing virtual experimentation platforms that complement the absence of physical infrastructure. This diversity of approaches reinforces the importance of contextualized solutions that account for the particularities of each educational reality, avoiding the uncritical transplantation of models developed in privileged contexts (Tovar-Gálvez, 2022). The experience of the science teacher network in the Zona da Mata region of Minas Gerais (Silva et al., 2024) demonstrates how bottom-up strategies can generate more sustainable solutions adapted to local needs (Ghins, 2023).

Numerous imbalances were revealed in the review. Problem diagnoses are abundant (Albano & Delou, 2021; Honório, 2024; Silva et al., 2020), but interventions leading to problem-solving are rarely documented, leaving gaps in application and evaluation. Likewise, there is geographic concentration of investigations, with a predominance of research carried out in Brazil, limiting broader international comparisons. These gaps point to the need for investment in transnational collaborative research that can map strategies across different contexts. The experience of international research networks in science education suggests that comparative approaches can yield valuable insights for overcoming common challenges, particularly regarding the integration of scientific knowledge with local knowledge (Schoonenboom, 2024).

Institutional responses to the science education crisis often oscillate between denying limitations and resigning to scarcity. However, experiences such as "community laboratories" in Brazil's semi-arid region (Honório, 2024) point to alternatives that acknowledge local conditions without abandoning scientific rigor. The case of Indonesia (Mohzana et al., 2023) further demonstrates that interventions focused on optimizing existing resources can be more cost-effective than large-scale infrastructure investments. The historical persistence of challenges in experimental teaching reveals a worrisome gap between diagnosis and effective action. While access to basic education has expanded globally in recent decades (UNESCO, 2024), the quality of science education in peripheral regions remains stagnant. The COVID-19 pandemic acted as a contradictory driver: on one hand, it exacerbated existing inequalities (Mavuru & Ramaila, 2022), but on the other, it accelerated the adoption of hybrid methodologies and the establishment of new educational partnerships (Cardoso et al., 2024). This temporal analysis suggests that lasting solutions will require not only material resources but also transformations in educational governance structures, with greater participation of local actors in decision-making processes. A longitudinal study conducted in rural schools in South Africa (Soyikwa & Boateng, 2024) demonstrates that sustainable interventions require time to consolidate cultural changes in pedagogical practices.

The implementation of functional laboratories in low-income schools remains a global challenge, and the debate on alternatives must take financial sustainability and scalability into account. Experiences with low-cost materials have shown effectiveness on a small scale, but their feasibility in large education systems remains questionable without continued institutional support (Honório, 2024). In this context, the Indonesian case of optimizing existing resources (Mohzana et al., 2023) is particularly instructive, showing that efficient management can be more cost-effective than mere infrastructure expansion. The suggestion of combining digital technologies with local resources may offer the best cost-benefit ratio in contexts of scarcity (Comeaga, 2022). The integrated analysis of these diverse experiences reveals that the challenges of science teaching transcend the mere lack of material resources. They require a profound reassessment of what constitutes quality science education in different contexts (Lira & Senna Junior, 2024). The most viable solutions appear to be those that emerge from dialogue between fundamental scientific principles and the material and cultural possibilities of each specific context (Martire et al., 2024). This perspective underscores the need for more flexible and context-sensitive educational policies capable of recognizing and supporting pedagogical innovations that flourish even under adverse conditions (Gonçalves et al., 2024). The Namibian case (Ndjangala et al., 2021) shows that even in extremely unfavorable contexts, a combination of strategic investments, contextualized teacher training, and valuing local knowledge can generate improvements in science education quality.

Finally, it is worth considering the pronounced geographic asymmetry in reports on challenges in science teaching: while developing countries such as Brazil (Rolim, 2025), Namibia (Ndjangala et al., 2021), and Rwanda (Munyemana et al., 2022) extensively document their laboratory limitations, literature from developed nations is notably silent on equivalent difficulties. This disparity does not necessarily reflect the complete absence of challenges in wealthy countries, but perhaps a research gap regarding critical dimensions such as the taken-for-granted adequacy of infrastructure, the focus on advanced issues—such as artificial intelligence in education—at the expense of basic problems, and the underrepresentation of these countries in reviews of educational precariousness. Available studies show that while Brazilian rural schools lack science laboratories (Camargo et al., 2024), Finland, by contrast, is widely recognized for its high-quality educational infrastructure, with strong investment in modern, well-equipped learning environments (OECD, 2024), creating an imbalance in academic production on the subject. However, even in privileged contexts, challenges persist, such as underutilization of laboratory spaces due to excessive bureaucratic protocols, difficulties integrating advanced digital technologies into traditional pedagogical practices, and obsolete equipment in schools located in urban peripheries (Giovanni, 2021). The invisibility of these discussions in international literature creates the false perception that laboratory-related problems are exclusive to the developing world, when in reality they manifest differently across contexts.

5. Conclusion

This scoping review mapped the difficulties in teaching and learning within laboratory environments. The results consolidate a consensus that the challenges are multifaceted, interrelated, and perpetuated by a cycle of deficiencies. Material limitations—such as the absence of laboratories, shortages of supplies and equipment—constitute the most frequently observed barrier, documented in contexts as diverse as Brazil and other resource-limited countries. This infrastructural precariousness forces teachers to improvise and prevents the implementation of practical activities, confining science teaching to a predominantly theoretical dimension that fails to meet students' expectations. To this limitation is added the insufficiency of teacher training and pedagogical preparation, as many educators have not received specific instruction for conducting experiments safely and within an investigative framework. This scenario is further aggravated by management and safety issues, including poor stock administration, inadequate waste management, and the absence of an institutionalized biosafety culture, exposing educators and students to avoidable risks. Collectively, these factors create an environment that demotivates students and overburdens teachers, undermining the laboratory's role as a fundamental space for the integration of theory and practice.

The main limitations of this study lie in the very nature of the synthesized evidence. The final sample, although geographically diverse in scope, was numerically modest, reflecting the scarcity of published empirical literature directly addressing the research question with the rigor required for inclusion. The concentration of studies in low- and middle-income contexts—particularly Brazil—limits the generalization of findings to realities with adequate infrastructure, where challenges may differ, such as the integration of advanced technologies or bureaucratization of access. Furthermore, the reliance on self-reports from teachers and students as the primary data source may introduce perception biases, in which difficulties could be over- or underestimated. Finally, the temporal cut and the exclusive focus on in-person education may have excluded relevant discussions on hybrid or virtual solutions that gained strength in the post-pandemic period.

To advance in addressing the mapped problems, future research should focus on investigating interventions and evaluating their impacts. Priority should be given to the development and testing of context-sensitive teacher training models that equip educators with the skills to act creatively in scenarios of material restriction, moving beyond complaints to proposing solutions. Studies that assess the effectiveness and scalability of low-cost strategies and alternative experimental kits are necessary to transcend the scope of experience reports. In parallel, research should investigate models of collaborative management for school laboratories and interinstitutional partnerships that can optimize resources and share expertise. Finally, there is a need for comparative international research contrasting successful public policies from different countries, identifying transferable elements that may inform the creation of more effective national guidelines for practical science teaching.

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