TYPE Systematic Review
PUBLISHED 10 July 2024
DOI 10.3389/feduc.2024.1363132

OPEN ACCESS

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RECEIVED 29 December 2023
ACCEPTED 28 June 2024
PUBLISHED 10 July 2024

CITATION
Alberto MCL, Viviana BVC, Vladimir BEC and Fernanda PAP (2024) Innovative strategies to strengthen teaching-researching skills in chemistry and biology education: a systematic literature review.
Front. Educ. 9:1363132.
doi: 10.3389/feduc.2024.1363132

Innovative strategies to strengthen teaching-researching skills in chemistry and biology education: a systematic literature review

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The dynamic field of scientific education, particularly in chemistry and biology, demands the implementation of innovative teaching strategies, driving the need for continuous research to enhance skills in both educators and students. This systematic literature review (SLR) delves into the evolving landscape of chemistry and biology education research, shedding light on key trends, strategies, and skills. Employing the PRISMA methodology, we scrutinized 81 papers to assess the employment of resources, technologies, and methods conducive to effective learning and research. Searches were conducted in the Scopus and Google Scholar databases, with inclusion criteria spanning English and Spanish studies from the last five years. The analysis reveals a notable shift in recent years, emphasizing the diversification of instructional approaches, integration of sustainable practices, and a heightened focus on fostering essential research skills for both educators and students. The study underscores the significant adaptation to digital tools and virtual environments, potentially influenced by the challenges posed by the COVID-19 pandemic. Remarkable findings include the growing importance of cognitive, social, and emotional competence in student development. This work provides valuable insights for educators, researchers, and policymakers cross-talking the dynamic intersection of teaching and research in chemistry and biology education.

Systematic review registration: Identifier 001-RS-FCIC-PQB-UNACH-2023.

KEYWORDS

chemistry and biology education, researching, strategies, pedagogical innovations, skills

1 Introduction

Education serves as the foundation for national development. In an ever-evolving world marked by daily scientific breakthroughs, the methodologies employed in teaching the sciences must evolve alongside, demanding constant innovation and adaptability. A key aspect of educational goals involves the implementation of teaching strategies to reinforce skills such as curiosity, observation, interpretation, and the cultivation of an open-minded approach

(Johnson, 1962). These skills are key not only for the academic journey but also for inculcating an attitude that propels students towards greater success in accomplishing their own goals and progressing in their career path.

Chemistry and biology are both challenging sciences that require sophisticated pedagogical methods and models for a complete understanding since they involve sub-microscopic, macroscopic levels, and even symbolic mechanisms (Johnstone, 1991; Senisum et al., 2022). At the macroscopic level, chemical phenomena are directly observed through their visible properties, such as changes in state, color, density, temperature, and flammability, which facilitates students' learning through direct perception. At the submicroscopic level, models explain these properties based on the arrangement and behavior of ions, atoms, and molecules on a nanometric scale. The symbolic level employs equations and chemical formulas to mathematically represent the phenomena observed and explained at the other two levels. It is crucial for students to deeply understand chemistry by integrating the macroscopic, submicroscopic, and symbolic levels into their learning (Bedin et al., 2023).

The role of teachers becomes essential to properly transmit or inhibit learning (Blonder et al., 2023). Adopting new strategies and technologies strongly supported education continuing during the COVID-19 pandemic (Ballaz et al., 2023) which has already given good results, and such technologies have been implemented in the current education landscape (González-Villavicencio and Estrella-Flores, 2023).

A notable example of the integration of new technologies and strategies is blended learning, an educational approach that supplements traditional in-person instruction with online teaching (Bautista-Arpi et al., 2023; Setiawan et al., 2023). This integration demands the implementation of various strategies, including the incorporation of Information Communication Technologies (ICTs) into teaching and learning processes (Ratheeswari, 2018). Concurrently, continuous advancements in pedagogical strategies have raised a dynamic equilibrium among Technology, Pedagogy, and Content Knowledge (TPACK framework) (Koehler and Mishra, 2009). Another innovative method involves the utilization of Customized Pedagogical Kits (CPKs), allowing the tailoring of pedagogical activities to meet the unique needs of students, thereby enhancing comprehension of complex concepts (Easa and Blonder, 2022). This multifaceted integration of frameworks and tools reflects an ongoing commitment to enriching the educational landscape through thoughtful and adaptive methodologies.

The distinctiveness of scientific pedagogy, particularly in chemistry and biology, lies in its emphasis on teaching students not only what to learn but also how to learn effectively. The objective is to instill in students the ability to unravel ideas, disseminate information, and articulate topics related to the everyday world, all rooted in scientific evidence. Crucially, involving students in early research is paramount to fostering the discovery of knowledge and cultivating scientific skills, commonly referred to as science process skills (Funk, 1985). Chemistry and biology necessitate experiences beyond the confines of the traditional classroom and textbooks. Engaging in experimental practices, often guided by "cookbook" instructions, becomes instrumental. These hands-on experiences in the laboratory not only provide a platform for exploring intriguing practices but also serve as a catalyst for discoveries or simply, the joy of learning. Therefore, laboratory practices, or practical work, can serve as a bridge, enabling teachers to connect their instructional methods with their research duties (Bradforth et al., 2015).

A limited number of systematic literature reviews (SLRs) addressing the interplay between teaching and research processes in chemistry and biology education have been conducted thus far. For example, Chiu (2021) explored 45 papers on digital technologies in chemical education and identified augmented reality (AR) and virtual reality (VR) as prominent technologies over the past decade. Additionally, eye-tracking experiments and learning analytics were recognized as supporting educational research (Chiu, 2021). Bellou et al. (2018) conducted an SLR of 43 papers, providing a comprehensive overview of digital learning technologies in chemistry. Their analysis emphasized constructivism and highlighted visualizations and simulations as the primary technologies for representing the abstract scientific world (Bellou et al., 2018). Agustian et al. (2022) focused on laboratory competence, reviewing 136 papers and highlighting disciplinary learning, higher-order thinking, epistemic learning, transversal competence, and the affective sphere. Oliveira and Bonito (2023) concentrated on practical work in science education, reviewing 53 studies and emphasizing the importance of material handling, competence in scientific processes, enhanced understanding of the nature of science, and the mobilization of scientific knowledge together with minds-on method (Oliveira and Bonito, 2023).

Socio-scientific issues in chemistry education were explored by Çalık and Wiyarsi (2021), who analyzed 65 papers, emphasizing opportunities to make chemistry learning and chemical literacy sustainable (Çalık and Wiyarsi, 2021). In biology, Setiawan et al. (2023) stood out by reviewing 23 papers related to blended learning implementation, highlighting challenges, diverse strategies employed, and perceptions. Gumanová and Šukolová (2022) conducted an SLR analyzing the competence of university teachers based on 35 studies as a means of assessing teaching quality.

Despite many SLRs exploring multiple databases, the overall number of articles is often limited, and many fail to provide a robust quality assessment process, posing a risk of bias. This paper introduces, for the first time, a comprehensive compilation of strategies applicable across various learning environments within the experimental sciences of chemistry and biology. Our analysis of 81 studies obeys the rigorous systematic structure outlined in the PRISMA statement (Page et al., 2021). This approach enables the presentation of quantitative insights into the key characteristics of the state-of-the-art in the last five years. Additionally, it unveils the principal strategies, tools, and skills crucial for fostering a culture of learning and teaching grounded in research.

Conducting a literature review on strategies to strengthen teaching-research skills in chemistry and biology education is crucial for identifying trends and gaps in research, understanding the population categories and specific areas most benefited, and recognizing the innovative methodologies and tools utilized. This will enhance the professional development of educators, improve educational quality, and ensure that policy and curricular decisions are based on robust evidence, aligning with the needs of society and the labor market. Furthermore, these disciplines are not only essential for understanding the natural world and scientific innovation, but they also serve as cornerstones in shaping future scientists and informed citizens. Integrating research into teaching not only enhances students' theoretical and practical understanding but also fosters the development of critical skills such as analytical thinking, problem-solving, and creativity. This not only prepares students better for careers in the sciences but also promotes a culture of research and discovery from an early age, crucial for addressing global challenges and advancing scientific and technological knowledge in the future.

The present SLR aims to analyze a compendium of articles on the current strategies for educational research in chemistry and biology to improve learning environments and strengthen the research abilities of chemistry and biology pedagogues. Through the present SLR, we answer the following five (5) research questions (RQ):

> **RQ1:** What are the bibliographic characteristics (country, year of publication, publishing journal, and main keywords) of research in chemistry and biology education?
>
> **RQ2:** What are the main population categories and specific areas of chemistry and biology in the research?
>
> **RQ3:** What research design strategies are employed in research in chemistry and biology education?
>
> **RQ4:** What tools are used to promote innovation in teaching and research in chemistry and biology?
>
> **RQ5:** What are the key skills to strengthen the teaching-research process in chemistry and biology?

2 Methods

The PRISMA methodology was employed to conduct the research, ensuring transparency and reproducibility in the literature review. This approach establishes clear steps to identify, select, evaluate, and synthesize relevant studies, reducing bias and ensuring the quality of the review process (Page et al., 2021). By following the PRISMA methodology, the identification of pertinent sources of information is promoted, enhancing the robustness of the research by relying on solid evidence. Furthermore, it facilitates the reproducibility of results, contributing to the advancement of knowledge in the field and their effective utilization by other researchers and professionals in the future.

2.1 Sources of information and eligibility and exclusion criteria

For this research, scientific databases Scopus and Google Scholar were utilized, chosen for their recognition within the academic community due to the breadth and depth of their content, encompassing a wide variety of disciplines and publications from prominent global publishers. The data for this group were gathered on November 11, 2023. The same databases were subsequently employed for the extraction of candidate studies following the application of the search string on the same date. These databases aggregate information from prominent publishers globally, including but not limited to the American Chemical Society, IOP Publishing Ltd., MDPI, American Institute of Physics Inc., Oxford University Press, American Society for Cell Biology, Routledge, John Wiley and Sons Inc., Society for Research and Knowledge Management, International Council of Associations for Science Education (ICASE), Walter de Gruyter GmbH, among others.

Once the relevant sources of information were identified, criteria for both inclusion and exclusion were established through specific search parameters. These criteria were designed with the aim of selecting studies that were relevant, recent, and directly related to the topic under study. The development of clear and specific criteria helps to maintain uniformity in the sample, enabling a more precise and consistent evaluation of the results obtained.

The inclusion and exclusion criteria for the depuration of the articles are as follows:

Inclusion criteria:

- Research and empirical studies of research in chemistry and biology education
- Articles published between the years 2019 to 2023
- Articles written in English and Spanish language
- Journal articles, conference papers, thesis/dissertation
- Published articles

Exclusion criteria

- Studies with scopes that do not relate to education
- Retracted articles and errata
- Do not present a complete typical article structure
- Review articles, working papers, pre-prints, books, and book chapters
- Non-English and non-Spanish articles

To initiate the search for studies in the selected database, a specific process was undertaken. Firstly, a control group consisting of 20 studies was established to establish a foundation of information, keywords, and approaches closely linked to the research topic. From this initial selection, the most recurrent keywords were identified, which were then used in the search for relevant studies addressing the research questions. This preliminary step allowed for the construction of a well-founded search string. Subsequently, the identified keywords were grouped by thematic blocks, as presented below.

- **Focus**: "research tool" OR "research skill" OR "research strategy" OR "research instruments" OR "science process" OR "research"
- **Area**: "chemistry" OR "biology"
- **Population**: "professor" OR "teacher" OR "university" OR "education" OR "learning"

After finalizing this process, search strings were formulated for both the Scopus and Google Scholar databases, integrating the predefined inclusion and exclusion criteria. The ultimate search strings employed were as follows:

2.2 Scopus

(TITLE ("research tool" OR "research skill" OR "research strategy" OR "research instruments" OR "science process" OR research) AND

TITLE (chemistry OR biology) AND TITLE (professor OR teacher OR university OR education OR learning)) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2023)) AND (LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "Spanish"))

Total: 109 paper

2.3 Google scholar

allintitle: "research tool" OR "research skill" OR "research strategy" OR instruments OR "science process" + chemistry OR biology + university OR professor OR teacher OR university OR education OR learning.

Set up: Specific interval: 2019–2023

Search only pages in Spanish and English

Total: 50 paper

2.4 Search strategy and selection process

Once the search was completed, a total of 159 studies were retrieved. For the initial selection phase, the title, abstract, and keywords of each study were examined. In this review process, all four authors participated, each assuming specific roles as reviewer, arbitrator, and final decision-maker. In case of discrepancies between the reviewer and the arbitrator, additional discussions were held to reach a consensus. This also contributed to the appropriate selection of studies and the reduction of bias risk. The entire process was conducted manually, without using any automation tools.

Researcher 1	Collects and reviews studies from 1 to 40	arbitrates from 121 to 156
Researcher 2	Collects and reviews studies from 41 to 80	arbitrates from 81 to 120
Researcher 3	Collects and reviews studies from 81 to 120	arbitrates from 41 to 80
Researcher 4	Collects and reviews studies from 121 to 156	arbitrates from 1 to 40

2.5 Data collection process

The collection of studies involved obtaining the primary studies (81) in a PDF for-mat with complete text. Research papers specifying details such as the sample size, research strategies, tools used, and the results obtained in an educational context were preferred. Subsequently, we applied the content analysis method to each study. This analysis was carried out by the four authors of this article. The entire set of articles was distributed equally among the four researchers to collect. The complete table for data collection is available in the Supplementary material (SM1_PQB_Results) under the Data Processing tab.

2.6 Data items

The items under study in this research fall into four primary categories: general bibliometrics, educational context, strategies utilized in the teaching-research process within chemistry and biology education, and skills strengthened. General bibliometrics involves details such as the year of publication, source, publisher, country, and authors. The educational context was determined by the specified study group in each research, comprising students or teachers, and incorporating aspects related to the educational level, subject, and specific topic under analysis. The strategies were categorized into methods, techniques, pedagogical tools, and digital tools. Finally, the skills reported in each research were compiled and categorized. The processing of this information was supported by the Pandas package from Python v3.12. Some network visualizations were generated using VOSviewer software.

2.7 Study risk of bias assessment and effect measures

As mentioned earlier, for both the initial study selection phase and the primary study selection, a comprehensive review and analysis of the studies were conducted by the four authors of the study, who assumed specific roles as reviewers, arbitrators, and final decision-makers. In cases where discrepancies arose between the reviewer and the arbitrator, additional discussions were held to reach a consensus. This approach ensures the reduction of bias risk and ensures that the selected studies meet the inclusion criteria for the research. The implementation of clear and systematic procedures in its execution helped minimize the likelihood of biases introduced by the authors. Quality assessment was based on the representativity of each item, considering the total studies included in the review and the number of studies included in each research question, mean, median, and confidence ranges were computed for each RQ.

2.8 Synthesis methods

A comprehensive analysis of the 81 included studies was undertaken through a full-text examination. Each item was systematically tabulated within a matrix in Microsoft Excel that encompassed key details, including the title, author, country, utilized strategies (methods, techniques, tools, and skills), discipline, and educational level.

Researcher 1	Analyzes studies from 1 to 20	Arbitrates from 61 to 81
Researcher 2	Analyzes studies from 21 to 40	Arbitrates from 41 to 60
Researcher 3	Analyzes studies from 41 to 60	Arbitrates from 21 to 40
Researcher 4	Analyzes studies from 61 to 81	Arbitrates from 1 to 20

2.9 Reporting bias assessment

Bias reporting relied on evaluating the representativity percentage, which was computed based on the research papers' content capability to address the proposed RQs. For each specific RQ, assessment factors were calculated using a scale categorizing the quality of studies as high, medium, or low. The corresponding tables are presented in the Results section.

2.10 Certainty assessment

Certainty assessment relied on the careful selection of statistically representative groups of information extracted during the study processing. In other words, the trending parameters, capable of addressing the RQs, are highlighted in the main body of the present SLR. However, for a comprehensive overview of the processing and selection, a detailed table is provided in the Supplementary material, in the Excel workbook named SM1_PQB_Results.

3 Results

3.1 Study selection

Our cohort of candidate studies initially comprised 159 research articles obtained employing the search string as previously described. As shown in Figure 1, two duplicates were identified among the databases Scopus and Google Scholar and one document was unavailable. Following the screening process based on exclusion and inclusion criteria, 75 studies were excluded. After thorough individual analysis, 81 studies identified by type of research and design successfully addressed the research questions and fell within the scope of the study. Consequently, all 81 studies were retrieved as full-text documents and were considered as primary studies for comprehensive review.

3.2 Study characteristics

3.2.1 Bibliographic characteristics of research in chemistry and biology education (RQ1)

This review aims to comprehensively analyze the landscape of research in chemical and biological education over the last five years, as proposed in RQ1. Table 1 and Figure 2 provide a country-wise categorization, offering a geographical overview of the diversity within this field. Notably, the majority of articles originate from Asia (41.98%), followed by North America (34.57%), Europe (13.58%), Africa (6.17%), and South America (3.70%). Noteworthy is Indonesia's prominence as the leading contributor with 28 articles, surpassing the USA (23), Canada (5), Nigeria (4), and both Brazil and Germany (3 each). The significance lies in the observation that the top 10 contributing countries encompass a combination of developed and developing nations, as presented in Figure 2.

Figure 3 illustrates the trend in the number of publications reported in the current study over the past five years. It reveals a growth pattern, starting with 12 published studies in 2019, reaching a peak of 26 in 2021, and subsequently declining to 6 studies in the fall of 2023.

The journals that contribute to the majority of the articles presented in this SLR are presented in Figure 4. The analysis reveals a significant contribution of articles from the Journal of Chemical Education ($n = 11$ studies), followed by the Journal of Physics: Conference Series (8), with Education Sciences (5) in the third position. Figure 5 further outlines the primary publishers in the field over the last five years. Foremost among them is the American Chemical Society (ACS) ($n = 11$), succeeded by IOP Publishing Ltd. (7) from the United Kingdom, and in third place is MDPI (5) from Switzerland.

We conducted an analysis of keywords extracted from the studies within our SLR. In total, 406 keywords were identified from both author-provided keywords and indexed terms. The analysis focused on keywords appearing at least twice in the studies, resulting in the identification of 86 keywords meeting this frequency threshold. Figure 6 presents a network visualization illustrating the interconnections among these keywords, organized into four clusters normalized by association strength. The most frequent keywords are student/students (22), human/humans (16), biology (13), education (7), and university (6).

3.3 Results of syntheses

3.3.1 Population categories and specific areas of chemistry and biology present in research (RQ2)

After scrutinizing each of the 81 articles included in the SLR, our analysis, as shown in Figure 7, reveals that 60.49% of the educational research articles in chemistry and biology are centered on student-focused research. This is further broken down into research on undergraduate students (27), high school students (14), and senior high school students (8). Additionally, the remaining 39.51% examine the dynamics of teachers. Among these, a substantial number focus on pedagogical aspects related to prospective or future teachers (18), while 11 of them delve into teachers' aspects in general, and 3 are studies specifically centered on high school teachers.

Concerning the specific topics explored in the studies covered in this SLR, as shown in Table 2, it is noteworthy that 51.85% relate to the field of chemistry ($n = 45$), while 48.15% are centered on biology ($n = 36$). These results underscore a relatively even distribution of studies between the domains of biology and chemistry, indicating a diverse and comprehensive coverage of various research areas within each discipline. In the field of biology, alongside the prominent focus on basic biology (11.48%), which is essential for understanding fundamental life principles, there is significant interest in botanical studies (8.20%) and cellular biology (6.56%). These areas are critical both for preserving plant biodiversity and advancing our understanding of essential cellular processes.

Conversely, in the field of chemistry, in addition to the predominance of studies in general chemistry (21.31%), spanning from theoretical chemistry to practical applications across various industries, there is notable attention to studies in environmental chemistry (11.48%) and analytical chemistry (8.20%). These areas are crucial for addressing environmental challenges and enhancing chemical analysis techniques, respectively, reflecting a comprehensive approach in the application of chemistry to solve contemporary issues.

Notably, we introduced a classification system to delineate specific aspects related to education in chemistry and biology. This revealed that the majority of studies primarily concentrate on promoting scientific research within their contextual domain

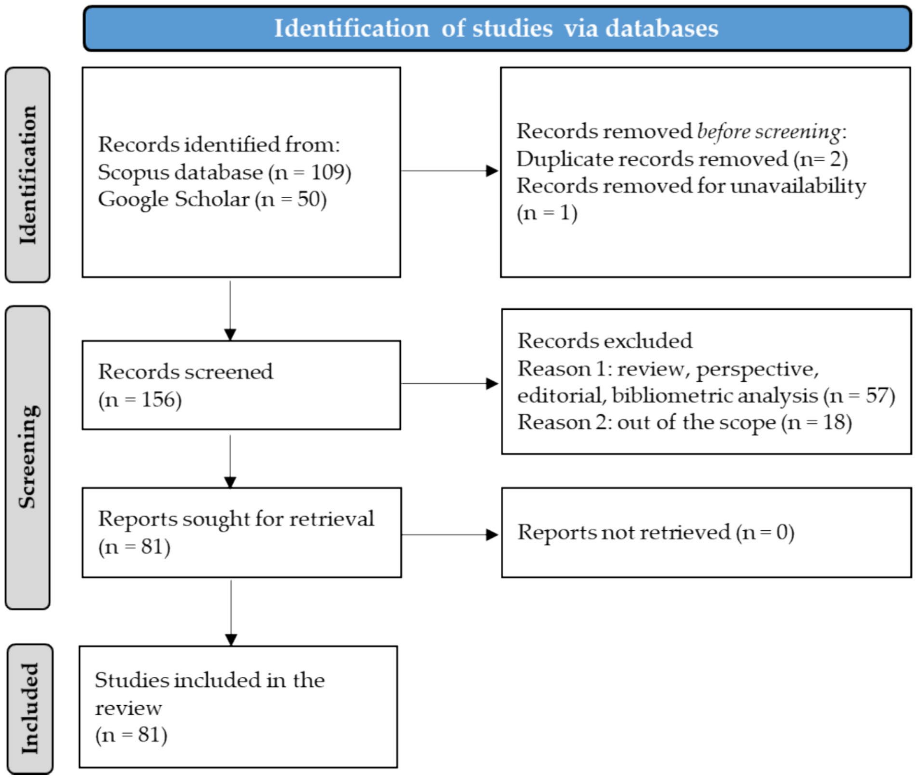

FIGURE 1
PRISMA flow diagram of the literature selection process.

(21.31%). Furthermore, there is discernible interest in themes such as citizen engagement, diversity, and inclusion within these sciences (9.84%). Lastly, the incorporation of technologies in education emerges as an additional area of focus, albeit to a lesser extent (3.28%).

3.3.2 Research design strategies are used in chemistry and biology education research (RQ3)

In addressing RQ3, we delved into the strategies employed by researchers in their study designs. To systematically categorize the extracted research methods and techniques within the educational context, we based on Cook and Cook's (2016) classification framework. Our analysis unveiled that a predominant portion of the studies was evenly distributed between descriptive and qualitative methodologies (58.82% each). Subsequently, we observed studies categorized as experimental accounting for 27.45%, while relational studies constituted 3.92% as presented in Table 3.

Notably, a trend emerged wherein researchers embraced theoretical and methodological frameworks, such as guided-inquiry learning ($n=7$), undergraduate research experience (URE) (5), research-based studies (5), course-based research (CURE) (3), project-based studies (4), research-oriented collaborative inquiry (REORCILEA) (3), design-based research (3), and participatory action research (PAR) (2). Additionally, within the methodological framework, a significant proportion adopted quasi-experimental studies (6), alongside the utilization of the purposive sampling technique (3).

3.3.3 Tools to promote innovation in teaching and researching in chemistry and biology (RQ4)

Table 4 illustrates an array of tools that have the potential to foster an efficient educational environment and promote research among both teachers and students. Our classification system, derived from an analysis of 81 studies in our SLR, identifies nine distinct categories based on tools described in the reviewed literature. The majority of articles concentrate on tools beneficial to conducting research. A significant portion (85.71%) delves into comprehensive descriptions of data collection tools, emphasizing the prevalent use of questionnaires, surveys, and testing, particularly pre-test and post-test methodologies applied during the evaluation of pedagogical techniques.

Furthermore, data processing (7.14%) is facilitated by digital tools such as Python with associated packages like Matplotlib, Seaborn, and Pandas, as well as Amberscript for interviews, and software tools like MAXQDA and Provalis. A notable percentage (20%) focuses on data analysis tools to advance scientific exploration, with preferences for SPSS, R, Python, and G*Power software. Additionally, there are studies about tools related to study design and development (2.86%), predominantly grounded in pre-existing research.

Moreover, Table 4 presents tools to strengthen chemical and biological education. Notably, formative evaluation tools are central, constituting 38.57% of the highlighted tools. These tools include the preparation of curricula to uphold quality education, well-structured lesson plans, and strategic testing methodologies.

The past five years have witnessed the prominence of virtual learning environments (18.57%), with platforms like EDMODO, Zoom, MS Teams, e-magazines, and YouTube playing pivotal roles.

TABLE 1 Classification of the studies by countries.

Country	Studies	N° of studies	Representativity (%)
Europe			
Germany	Zowada et al. (2020), Graulich et al. (2022), and Linkwitz and Eilks (2022)	3	13.58
Spain	Amer et al. (2022) and López-Martínez and Martínez (2023)	2	
Ukraine	Nechypurenko et al. (2020, 2023)	2	
Finland	Pernaa et al. (2022)	1	
Netherlands	Van Dulmen et al. (2022)	1	
Serbia	Zeljic (2021)	1	
United Kingdom	Parsons and Sarju (2023)	1	
North America			
USA	Burley et al. (2019, 2021), Mack et al. (2019), Aguillon et al. (2020), Guarracino (2020), Kottmeyer et al. (2020), Ross et al. (2020), Rubush and Stone (2020), Welch (2020), Guo et al. (2021), Lee et al. (2021), Scott et al. (2021), Segura-Totten et al. (2021), Vance-Chalcraft et al. (2021), Villalta-Cerdas et al. (2021), Barr et al. (2022), Chen-Musgrove et al. (2022), Donegan et al. (2022), Hamers et al. (2022), Kulesza et al. (2022), Polik and Schmidt (2022), Stelz-Sullivan et al. (2022), and States et al. (2023)	23	34.57
Canada	Weir et al. (2019), Elbassiouny et al. (2020), Hills et al. (2020), Deng et al. (2021), and Vanderzwaag et al. (2021)	5	
South America			
Brazil	Baptista and Araujo (2019), Sentanin et al. (2021), Bedin et al. (2023)	3	3.70
Asia			
Indonesia	Asy'ari et al. (2019), Hadisaputra et al. (2019), Irwanto et al. (2019), Lukitasari et al. (2019), Narulita et al. (2019), Ramdiah and Royani (2019), Susanti et al. (2019), Fauzi et al. (2020), Hariati et al. (2020), Juniar et al. (2020, 2021), Herda et al. (2020), Mataniari et al. (2020), Permatasari et al. (2020), Rohaeti and Prodjosantoso (2020), Anita et al. (2021), Aripin et al. (2021), Aryanti et al. (2021), Huda and Rohaeti (2021), Ivana et al. (2021), Putri et al. (2021), Sugiati and Harahap (2021), Susilo and Sudrajat (2021), Widianti et al. (2021), Zulaikha et al. (2021), Maknun et al. (2022), Senisum et al. (2022), and Irwanto (2023)	28	41.98
Israel	Rap et al. (2020) and Blonder et al. (2023)	2	
Thailand	Kaanklao and Suwathanpornkul (2020)	1	
India	Savarimuthu and Susairaj (2022)	1	
Kazakhstan	Salybekova et al. (2021)	1	
Philippines	Garcia et al. (2022)	1	
Africa			
Nigeria	Abduldayan et al. (2021), Abumchukwu et al. (2021), Ewim and Opateye (2021), and Ngozi (2021)	4	6.17
Tanzania	Beichumila et al. (2022)	1	

Given the significance of practical work in both chemistry and biology, a considerable focus (17.14%) has been placed on the implementation of simulations and virtual laboratories in classrooms. Notable examples include A-Frame, VLab VCL, ChemCollective computational simulations, and augmented reality applications.

Moreover, interactive and visualization platforms (10%) contribute to the learning experience through tools such as interactive boards, Lucidchart, spider chart diagrams, and apps like iNaturalist. Lastly, communication and collaboration platforms (11.43%) emerge as crucial tools in promoting learning, teaching, and research. Among these, social networks such as Twitter, Facebook, Instagram, and WhatsApp are widely utilized. Additionally, collaborative programs like the Bridge to the Chemistry Doctorate program (United States), the Chemistry Opportunities (CHOPs) program (USA), and the SignUpGenius platform have been well-described in the studies.

3.3.4 Key skills to strengthen the teaching-research process in chemistry and biology (RQ5)

Table 5, presents the key skills to strengthen the teaching-research process in chemistry and biology. Our examination of the articles in the SLR has led to the identification of six primary classifications. Notably, research skills (59.26%) emerge as the most prominently emphasized competence to be cultivated. These encompass the underpinnings of the scientific method, including data collection, management, and visualization, interpreting data, experimental design, hypothesis formulation, ethics, and science process skills (SPS).

Furthermore, cognitive and thinking skills (41.98%) stand out as imperative for successful learning, including critical thinking, analytical skills, creativity, reasoning, and problem-solving skills. Communication skills (39.51%), such as argumentation, reporting,

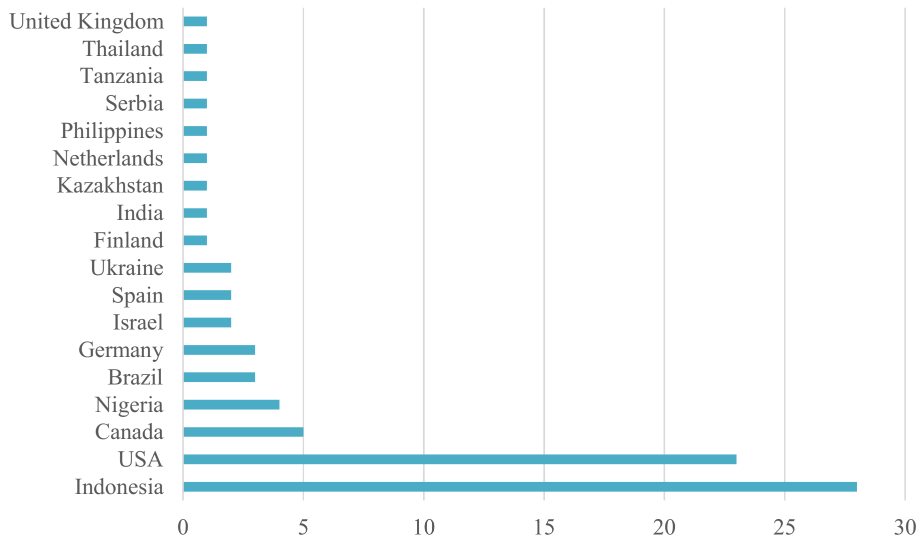

FIGURE 2
Number of studies by countries.

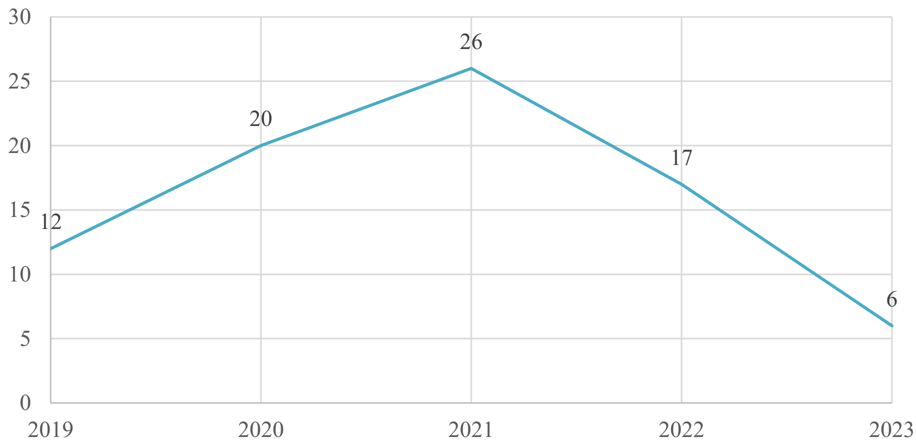

FIGURE 3
Number of studies published from the year 2019 to 2023.

reading, and oral and written communication, are highlighted as essential for fostering research within the educational environment.

Equally important are social and emotional skills (34.57%), emphasizing skills like leadership, relationship-building, and teamwork in the classroom environment. Authors underscore the significance of cultivating positive attitudes, motivation, inclusivity, and acceptance of differences, including gender identity, as crucial elements in the contemporary educational landscape.

Additionally, in chemical and biological education, planning and managing skills (18.52%) emerge as key competence. The authors also underscore the importance of teaching and pedagogy skills (6.17%), emphasizing the significance of instructional competence in the educational landscape. Finally, technological skills (4.94%) are highlighted for their importance, particularly in employing information and communication technologies (ICTs). The authors also stress the encouragement of implementing technological knowledge and multimedia tools for effectiveness in teaching and research.

3.4 Risk of bias in studies

The risk of biases in the studies included in this SLR underwent a rigorous peer review process among the authors. The outcomes of the representativity of the studies are presented in Table 6 to assess the quality of the full-text articles. As shown, only 50.94% of the total candidate studies were selected for in-depth analysis, with 49.06% excluded during the depuration process based on inclusion and exclusion criteria. These decrease in the number of studies implies that the search strategy accurately aligns with our RQs, as well as supporting the employment of a stringent methodology in identifying and selecting studies. This supports confidence in the representativeness and comprehensiveness of the final sample.

Furthermore, the quality assessment also encompassed the content of the primary studies based on their relevance to addressing the RQs, as outlined in Table 7. In this context, RQ1 achieved a

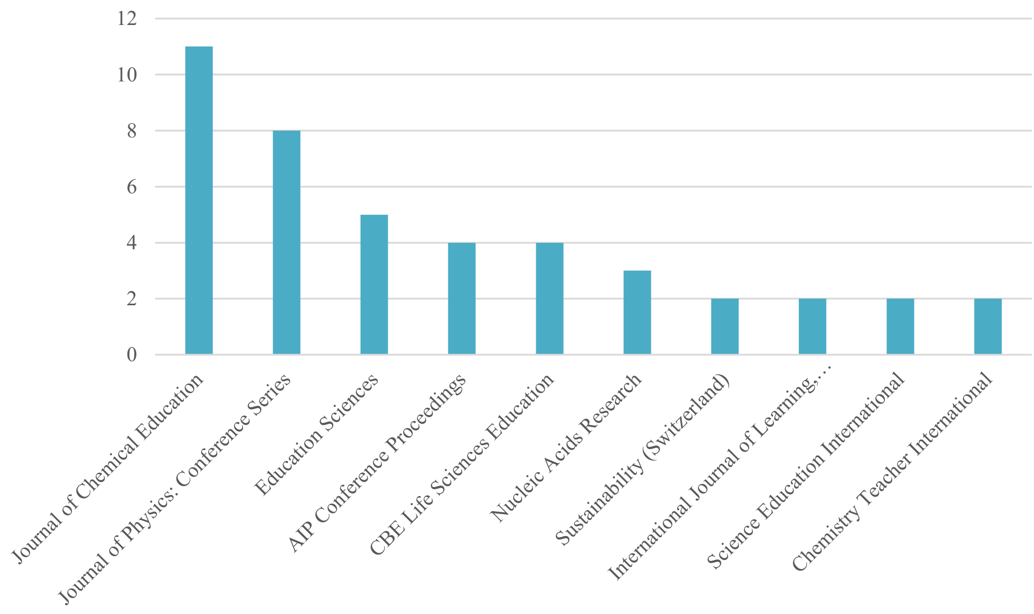

FIGURE 4
Top ten preferred journals for publishing in the field.

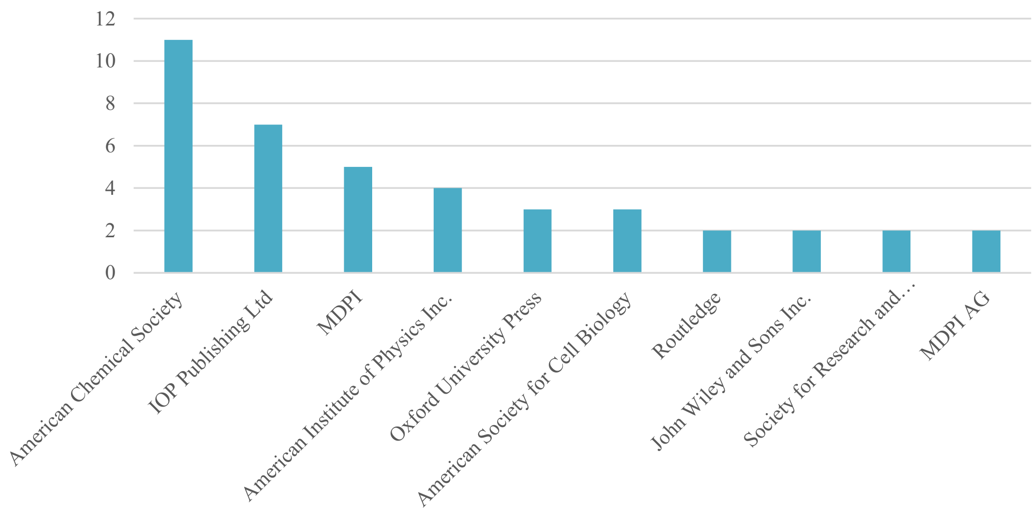

FIGURE 5
Top ten publishers of the reviewed articles.

representativity average of 20%, RQ2 of 8.52%, RQ3 of 37.25%, and RQ4 of 23.49%. Consequently, only the representative items in each classification were reported in the body of this research. Additionally, documents with retraction letters and errata were excluded from this study.

3.5 Reporting biases and certainty of evidence

A risk assessment analysis was conducted for each item of every RQ, and the data is summarized in Table 8, including the percentage of studies addressing each RQ regarding the total of studies (81) and the number of PSs per RQ. It is noteworthy that the results are considered significant only if they fall within the medium to high-quality range, as outlined in Table 7. An exception is made for items from RQ1, specifically the countries, which were comprehensively included in Table 1 and Figure 2.

4 Discussion

Research in science education, particularly in chemistry and biology, has become crucial in our ever-changing world. This research

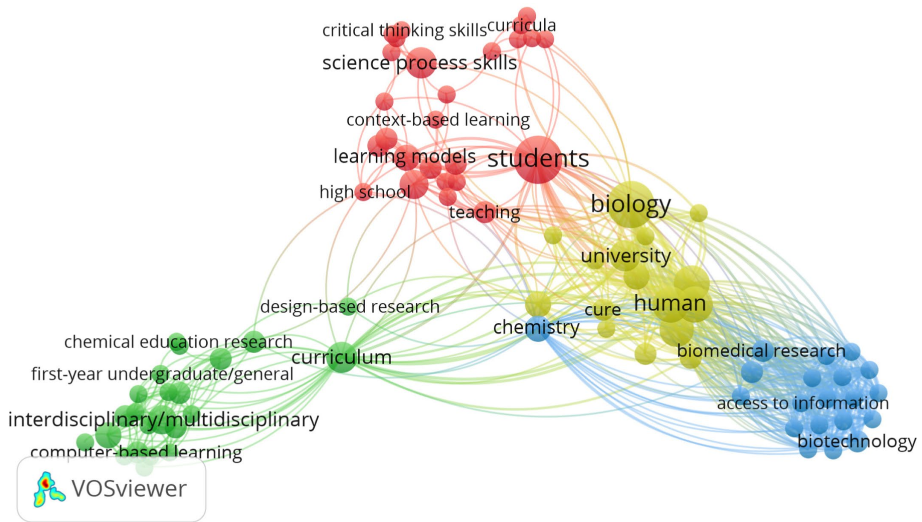

FIGURE 6
Network analysis of keywords.

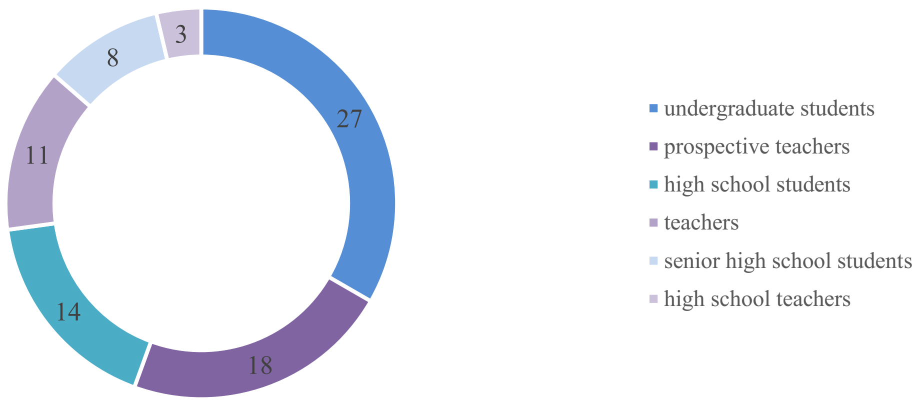

FIGURE 7
Educational level of the sample population described in the reviewed articles. Blue palette represents students' analyses and purple one, teachers.

enables educators to develop, assess, and enhance teaching practices for effective learning. Investing in education is a paramount effort to drive the progress of nations. Therefore, identifying and comprehending current trends in teaching-research practices is essential for refining our methodologies and implementing positive changes in the classroom environment. Our review provided an overview of the current landscape of research in chemistry and biology education based on 81 research articles collected following the systematic methods proposed in the PRISMA statement. Through our bibliometric analysis, a noteworthy pattern emerged, challenging the conventional assumption that developed countries lead in educational research (Zhang et al., 2016). Our findings revealed a significant investment in educational research by several third-world countries even after restricting the search string to English and Spanish studies. While established nations such as the USA, Germany, and Spain still feature prominently in the top 10 contributors, Indonesia took the lead as the major publisher in the field over the last five years. This marks a notable shift, with other developing countries like Nigeria, Brazil, Israel, and Ukraine also making substantial contributions to research efforts in the field in accordance with the sustainable development goals (Kopnina, 2020; United Nations, 2023).

In our exploration of preferred journals and publishers, we aimed to contribute to the comprehensive evaluation of the scholarly landscape in the field. The inclusion of well-known journals adds depth to the synthesis of research findings. Notably, the prevalence of papers from these journals underscores their significance within the academic ground related to our study. Moreover, our preference for publishers such as the American Chemical Society (ACS), IOP Publishing Ltd., and MDPI reflects a commitment to relying on sources known for their editorial rigor and scholarly contributions. This finding aligns with our goal of ensuring the robustness and meaningfulness of the literature reviewed, reinforcing the credibility and relevance of our synthesized research findings.

A notable trend observed over the last five years indicates a surge in the number of publications from 2019 to 2021, followed by a decline to the present year, 2023. This pattern can be attributed to the

TABLE 2 Specific disciplines in the educational context of chemical and biology.

Topic	Branch	Specific disciplines	Studies' ID	N° of studies	Representativity (%) studies addressing RQ2 = 61
Biology	Basic biology	General and foundational courses	PS3, PS25, PS26, PS35, PS76, PS78, PS61	7	11.48
	Botany	Botany, fungi affecting vegetables, plant cell material, plant physiology, pollinators	PS55, PS60, PS68, PS62, PS46	5	8.20
	Cell biology	Cell and molecular biology, structure and function of cells in the reproductive system, plant cell material	PS74, PS32, PS49, PS68	4	6.56
	Ecology and biodiversity	Ecology, ethnobiology, evolutionary biology and biodiversity, nature	PS42, PS67, PS77	3	4.92
	Physiology	Physiology, systems of the human body	PS12, PS53, PS28	3	4.92
	Microbiology	Protists, COVID-19 Literacy	PS81, PS72	2	3.28
Chemistry	General chemistry	Foundational and introductory	PS5, PS8, PS41, PS71, PS10, PS13, PS16, PS17, PS20, PS21, PS37, PS56, PS65	13	21.31
	Environmental chemistry	Atmospheric chemistry, environmental chemistry, green chemistry, green pesticides, chemical biology	PS63, PS2, PS39, PS50, PS70, PS52, PS57	7	11.48
	Analytic chemistry	Analytical chemistry practicum, qualitative chemistry, separating mixtures, separation techniques	PS51, PS22, PS69, PS80, PS23	5	8.20
	Structural chemistry	3D molecular structure, modern chemistry (spectroscopy and photochemistry), quantum chemistry	PS30, PS7, PS19	3	4.92
	Thermodynamic and kinetics	Chemical equilibrium, colligative properties, solutions	PS65, PS9, PS59	3	4.92
	Inorganic chemistry	Ionic Liquids, Oxidation State of CuS	PS1, PS31	2	3.28
Education support	Research in Chemistry and Biology Education	Science Process Skills (SPS), epistemic development, evidence validity, research data management, multidisciplinary research	PS42, PS45, PS54, PS36, PS33, PS73, PS14, PS24, PS47, PS38, PS20, PS15, PS27	13	21.31
	Citizenship and Inclusion	Citizen science, diversity and inclusion, ethnochemistry	PS42, PS29, PS43, PS44, PS48, PS73	6	9.84
	Technology	Information and Communication Technology (ICT); Cutting edge chemistry	PS40, PS4	2	3.28

influence of the COVID-19 pandemic (Aviv-Reuven and Rosenfeld, 2021), which prompted a significant shift in the traditional classroom environment toward online teaching. This shift had a profound impact on the landscape of chemistry and biology education (Babosová et al., 2022; Broad et al., 2023), leading to increased research and innovations to adapt to the new educational paradigm. While the pandemic initially prompted a surge in research and advancements, the ongoing discoveries continue to exert a lasting impact on education, shaping the daily classroom experience. This underscores the importance of sustained research efforts in the field, as education needs to continually evolve and strengthen across various dimensions. This SLR comprehensively explored and addressed these aspects. While established techniques may prove effective, there is a continuous need for innovation in our classrooms to ensure dynamic and effective educational practices while continuing to publish and advance research.

Regarding the educational axes, our analysis covered a broad spectrum of articles, presenting a diverse array of studies that delved into pedagogical aspects including emerging collaborative research areas (Rodríguez-Cabrera, 2020). These studies ranged from investigations involving prospective teachers to those involving high school teachers and educators in general. Similarly, our examination of student-focused studies spanned from high school students through to university students. Indeed, a notable trend that has gained prominence in recent years is the integration of sustainable development principles (United Nations, 2023) into science teaching. Numerous studies have explored various facets of this interdisciplinary approach, with a particular focus on environmental and green chemistry that have received increasing attention, especially in recent years (Sjöström et al., 2015; Zuin et al., 2021). Additionally, the fields of ethnobiology and ethnochemistry have garnered attention, reflecting an increased interest in incorporating indigenous knowledge

TABLE 3 Strategies in educational research design based on Cook and Cook classification (Cook and Cook, 2016).

Classification	Strategies	Studies' ID	N° of studies	Representativity (%) studies addressing RQ3 = 51
Descriptive	Course-based research (CURE), purposive sampling technique, quantitative-descriptive research, participatory action research (PAR), assignment support, COPUS observations, cyclical development	PS30, PS61, PS32, PS50, PS57, PS76, PS17, PS20, PS48, PS39, PS49, PS41, PS77, PS52, PS37, PS55, PS73, PS45, PS70, PS44, PS63, PS65, PS66, PS47, PS3, PS64, PS23, PS19, PS25, PS58	30	58.82
Relational	Correlational descriptive, quantitative correlational	PS28, PS65	2	3.92
Experimental	Blended-problem-based, experimental designs, integrated course design, quasi-experimental research, Pretest-posttest design, project-based and problem-based learning	PS74, PS10, PS35, PS51, PS45, PS56, PS55, PS73, PS6, PS25, PS52, PS13, PS34, PS66	14	27.45
Qualitative	Undergraduate research experience (URE), design-based research, Research-Oriented Collaborative Inquiry, Guided inquiry, case-study, didactic engineering	PS33, PS19, PS23, PS46, PS1, PS11, PS12, PS13, PS14, PS3, PS22, PS45, PS7, PS28, PS51, PS30, PS17, PS63, PS44, PS29, PS77, PS24, PS67, PS5, PS37, PS56, PS39, PS25, PS48, PS50	30	58.82

and practices into science education which is known to improve education for sustainability in science (Zidny et al., 2020). The emphasis on nature-related approaches underscores a growing awareness of the importance of aligning science education with ecological considerations and fostering a deeper understanding of the interconnectedness between scientific knowledge and environmental sustainability. This evolving focus on sustainable development within science teaching reflects a broader recognition of the role that education plays in shaping environmentally conscious and socially responsible individuals. Furthermore, we observed a growing interest in educational support, particularly in parallel with content teaching. This support was primarily facilitated through the integration of ICTs. Moreover, there was a discernible emphasis on promoting science process skills (Asy'ari et al., 2019; Irwanto et al., 2019; Susanti et al., 2019; Herda et al., 2020; Juniar et al., 2020; Permatasari et al., 2020; Ivana et al., 2021; Ngozi, 2021; Widianti et al., 2021; Beichumila et al., 2022; Senisum et al., 2022; Irwanto, 2023), underlining a holistic approach to science education.

One of our primary objectives was to uncover the strategies applied in the current educational landscape of chemistry and biology that foster innovation and have the potential to promote changes in the field. Our findings reveal a prevalent focus among researchers on descriptive and qualitative research approaches. Various frameworks are employed, including Participatory Action Research (PAR) (Zowada et al., 2020; Linkwitz and Eilks, 2022), Undergraduate Research Experience (URE) (Welch, 2020; Aryanti et al., 2021; Guo et al., 2021; Hamers et al., 2022; Kulesza et al., 2022), Course-Based Research (CURE) (Hills et al., 2020; Rubush and Stone, 2020; States et al., 2023), research-based (Irwanto et al., 2019; Hamers et al., 2022; Parsons and Sarju, 2023), design-based (Kaanklao and Suwathanpornkul, 2020; Scott et al., 2021; Pernaa et al., 2022), and project-based (Zowada et al., 2020; Aryanti et al., 2021; Amer et al., 2022; Kulesza et al., 2022) methodologies. Additionally, guided-inquiry (Juniar et al., 2020, 2021; Widianti et al., 2021; Maknun et al., 2022; Polik and Schmidt, 2022; Senisum et al., 2022) learning and REORCILEA (Research-Oriented Collaborative Inquiry Learning Model) (Rohaeti and Prodjosantoso, 2020; Huda and Rohaeti, 2021; Irwanto, 2023) are actively utilized. Which has given promising results in similar contexts (Moran, 2007; Majgaard et al., 2011). Notably, quasi-experimental methods (Gopalan et al., 2020) and purposive sampling techniques are preferred in educational research. This diverse array of research strategies highlights the multifaceted nature of chemistry and biology education, demonstrating a commitment to innovation and a nuanced exploration of educational practices.

The tools employed in the teaching-research processes of chemistry and biology are of utmost importance, complementing the strategies applied in the field. While many studies contribute valuable strategies for researchers and students, with a focus on data collection, processing, and analysis, there is a slightly lesser emphasis on the design and development of research initiatives. Commonly used software such as Python, R, and SPSS remains prevalent in the data management educational scenario. Within the pedagogical aspect, the foundational role of formative evaluation tools in chemical and biological education is evident. Elements like curricula, structured lesson plans, and strategic testing methodologies are integral components supporting effective teaching and learning. Furthermore, virtual learning environments have emerged as indispensable tools (Caprara and Caprara, 2022), with platforms like EDMODO, Zoom, MS Teams, e-magazines, and YouTube playing key roles in enriching the educational experience. Notably, there is a growing emphasis on experimental learning in both chemistry and biology, and numerous papers introduce ground-breaking tools like virtual laboratories (Narulita et al., 2019; Nechypurenko et al., 2020; Chan et al., 2021; Garcia et al., 2022). These tools, such as A-Frame, VLab VCL, and ChemCollective computational simulations, have the potential to address challenges in developing countries that lack adequate science teaching instrumentation (Aslam et al., 2023).

The rise of virtual reality and simulations is commonly believed to contribute to knowledge acquisition, yet it is currently debated that causes less learning (Makransky et al., 2019). However, interactive platforms indeed enhanced the understanding of complex concepts. In the digital realm, communication platforms, particularly social

TABLE 4 Tools to promote innovation in teaching and researching in chemistry and biology.

Classification	Tools	Studies' ID	N° of studies	Representativity (%) studies addressing RQ4 = 70
Virtual learning environments	EDMODO, MS Teams, PadLet board, SMART Board interactive, Zoom, SignUpGenius platform, Youtube, e-magazines	PS31, PS72, PS71, PS8, PS59, PS57, PS61, PS79	13	18.57
Simulations and virtual laboratories	A-Frame, augmented reality, ChemCollective, computational simulations, PhET simulation, VLab VCL, WebMO (web-based interface), Yenka chemistry	PS69, PS79, PS10, PS18, PS23, PS30, PS7, PS19, PS52, PS66, PS59	12	17.14
Interactive and visualization platforms	Interactive boards, Lucidchart, spider chart diagrams, whiteboards, wikis, YouTube, iNaturalist	PS71, PS13, PS52, PS64, PS59, PS8, PS42	7	10.00
Formative evaluation tools	peer feedback sessions, self-evaluation, peer-mentoring, assignments, final projects, lesson plans, syllabus, tests, curriculum	PS71, PS48, PS16, PS17, PS20, PS21, PS46, PS63, PS67, PS76, PS79, PS53, PS29, PS38, PS12, PS81, PS3, PS6, PS11, PS15, PS65, PS61, PS39, PS35, PS66, PS36, PS31	27	38.57
Communication and collaboration platforms	Blogs, Facebook, Google Meet, Google Talk, Instagram, Skype, Twitter, WhatsApp, Zoom, Bridge to the Chemistry Doctorate program, Chemistry Opportunities (CHOPs) program	PS71, PS8, PS48, PS31, PS29, PS61, PS27, PS57	8	11.43
Study design and development	Research proposals, undergraduate research	PS38, PS2	2	2.86
Data collection	Questionnaires, surveys, tests (pre-test and post-test), semi-structured interview, Likert scale, Observation Checklist for Science Process Skills, observation sheet, rubrics, smartphones	PS11, PS71, PS10, PS14, PS60, PS16, PS34, PS39, PS67, PS38, PS43, PS55, PS12, PS19, PS9, PS73, PS56, PS65, PS51, PS74, PS61, PS24, PS22, PS35, PS37, PS42, PS52, PS54, PS70, PS21, PS17, PS31, PS36, PS62, PS72, PS78, PS79, PS29, PS81, PS58, PS59, PS69, PS18, PS32, PS20, PS25, PS26, PS40, PS46, PS68, PS77, PS3, PS66, PS63, PS76, PS49, PS27, PS2, PS8, PS57	60	85.71
Data processing	Amberscript, Python, MAXQDA, Provalis Qualitative Data Analysis (QDA) Miner	PS4, PS40, PS17, PS24, PS18	5	7.14
Data analysis tools	G*Power, R, SPSS, Provalis Qualitative Data Analysis (QDA) Miner	PS10, PS11, PS27, PS76, PS77, PS25, PS26, PS35, PS55, PS56, PS65, PS72, PS40, PS24	14	20.00

networks, continue to connect people and democratize knowledge. It is crucial to note that while digital tools and technologies do not directly cause learning, they provide affordances for specific tasks that, in turn, contribute to the learning process (Dalgarno and Lee, 2010). The integration of both strategies and tools is essential for fostering effective teaching-research practices in the dynamic landscape of chemistry and biology education.

One of the most significant contributions of the present SLR lies in identifying key competence or skills outlined in the literature that are considered essential to encourage in both educators and students. A consensus among many studies underscores the critical importance of promoting research skills encompassing the entire scientific method application process, from formulating hypotheses and making predictions to data collection, processing, and drawing conclusions. Notably, ethical considerations are also underscored as integral to this skill set. There is also a lesser but still noteworthy emphasis on planning and managing skills, which extend beyond the classroom setting and have broader implications. Cognitive and thinking skills, often referred to as high-order thinking skills (HOTs) (Ramdiah and Royani, 2019), assume a central role in the educational discourse. Cultivating creativity, problem-solving abilities, critical thinking, and reasoning is deemed imperative to cultivate by students in the classroom. Effective communication is an imperative skill both within the classroom environment and beyond. This encompasses promoting argumentation skills, oral communication, reading comprehension, and written communication. Moreover, social and emotional skills have gained increased relevance (Ingram et al., 2021), extending further than the conventional focus on productivity-related aspects

TABLE 5 Skills identified for strengthening teaching-researching process in chemistry and biology.

Classification	Specific skills	Studies' ID	N° of studies	Representativity (%) total studies = 81
Cognitive and thinking skills	Analysis, critical thinking, cognitive learning, creativity, evaluating, metacognition, problem-solving skills, reasoning, rationality	PS71, PS17, PS72, PS73, PS66, PS55, PS3, PS5, PS9, PS34, PS44, PS49, PS56, PS62, PS63, PS65, PS74, PS77, PS81, PS41, PS52, PS60, PS28, PS35, PS46, PS16, PS33, PS37, PS8, PS78, PS53, PS47, PS76, PS31	34	41.98
Research skills	Data collection, management, and visualization, interpreting data, experimental designing, hypothesis formulation, laboratory skills, ethics, predicting hypothesis, scientific training, science process skills (SPS)	PS18, PS17, PS42, PS43, PS24, PS23, PS32, PS30, PS36, PS37, PS19, PS61, PS59, PS79, PS1, PS2, PS13, PS21, PS57, PS80, PS6, PS54, PS51, PS62, PS47, PS60, PS67, PS69, PS26, PS27, PS40, PS25, PS63, PS70, PS72, PS52, PS15, PS33, PS20, PS3, PS9, PS22, PS28, PS35, PS55, PS56, PS65, PS68, PS73	48	59.26
Communication skills	Argumentation, communicating, disseminating, reporting, sharing results, reading, oral and written communication	PS17, PS49, PS52, PS3, PS36, PS54, PS68, PS6, PS21, PS22, PS25, PS34, PS47, PS57, PS61, PS63, PS66, PS71, PS78, PS19, PS39, PS50, PS44, PS51, PS45, PS29, PS46, PS5, PS20, PS58, PS43, PS27, PS37, PS38	32	39.51
Social and emotional skills	Acceptance of differences, attitude, belongingness, building relationships, collaboration, cultural, diversity, gender identity, leadership, motivation, positivity, teamwork, perseverance	PS55, PS26, PS75, PS29, PS25, PS21, PS24, PS32, PS34, PS42, PS49, PS76, PS73, PS77, PS67, PS81, PS20, PS38, PS56, PS58, PS5, PS48, PS9, PS41, PS44, PS47, PS50, PS61	28	34.57
Technological skills	ICT, technological knowledge, multimedia	PS40, PS8, PS70, PS10	4	4.94
Teaching and pedagogy	Instructional skills	PS40, PS8, PS60, PS66, PS67	5	6.17
Planning and managing skills	Organization, plan execution, implementation, participation, teamwork	PS46, PS33, PS45, PS57, PS39, PS43, PS6, PS51, PS25, PS10, PS44, PS47, PS50, PS55, PS61	15	18.52

TABLE 6 Quality assessment of the overall articles after peer-reviewing.

Study type	Number of studies	Percentage (%)	Description
Candidate studies	159	100.00	Studies resulting from the application of the search string
Selected studies	156	98.11	Unique studies without duplicates
After depuration of studies	81	50.94	Studies after reviewing the title, abstract, and keywords
Retrieved studies	81	50.94	Studies downloaded in full text
Primary studies	81	50.94	Studies reviewed in full text

like leadership, relationship-building, and teamwork. Contemporary emphasis is also placed on motivational skills, inclusivity, gender identity, and the acceptance of differences, recognizing these as key elements in personal development with substantial impacts in the educational environment.

We emphasize the active role of teachers and learners in knowledge construction, constructivism theories resonate with the diverse strategies, tools, and competence identified in the literature. The educational landscape, as illuminated through this systematic exploration, highlights the importance of fostering an interactive and engaging environment where learners are not just recipients but contributors to the knowledge-building process. Throughout chemistry and biology education, constructing innovative strategies in teaching and researching serves as a guiding principle for promoting meaningful learning experiences and cultivating a generation of learners equipped with the skills necessary for success in an ever-changing world.

5 Limitations and future research

Despite the thoroughness and rigor employed in this study, several limitations should be acknowledged. Firstly, the inclusion criteria may have introduced some degree of selection bias, as only studies published in English and Spanish were considered. This could potentially exclude relevant research published in other languages. Additionally, the focus on articles from peer-reviewed journals might have overlooked valuable insights from other databases or depending on our search string. Furthermore, the inherent heterogeneity in study designs, methodologies, and contexts across the included articles may limit the generalizability of the findings. Lastly, the rapidly evolving nature of educational technology and pedagogical practices implies that newer studies might provide insights not captured in this review. Despite these limitations, this study provides a valuable synthesis of the current

TABLE 7 Quality assessment of the content of the articles.

RQs addressing	Rep. average (%)	Median (%)	High confidence (%)	Medium confidence (%)	Low confidence (%)	Inclusion in the syntheses
RQ1	20.00	13.58	29.30–41.98	16.50–29.20	3.70–16.40	All countries are included in the analysis
RQ2	8.52	6.56	15.31–21.31	9.30–15.30	3.25–9.29	The first 5 techniques are included
RQ3	37.25	43.14	40.53–58.82	22.23–40.52	3.92–22.22	The first 6 strategies are included
RQ4	23.49	17.14	58.10–85.71	30.49–58.09	2.85–30.48	The first 8 tools are included

TABLE 8 Risk assessment of the items addressing each RQ.

Research question	Description	Number of studies addressing the RQ item	Percentage regarding the total of PS (%)	Percentage regarding the number of studies addressing each RQ (%)
RQ1. What are the main characteristics of research in chemical and biological education over the past five years?	Europe	11	13.58	13.58
	North America	28	34.57	34.57
	South America	3	3.70	3.70
	Asia	34	41.98	41.98
	Africa	5	6.17	6.17
RQ2. What is the scope of the educational context under consideration?	Basic biology	7	8.64	11.48
	Botany	5	6.17	8.20
	Cell biology	4	4.94	6.56
	Ecology and biodiversity	3	3.70	4.92
	Physiology	3	3.70	4.92
	Microbiology	2	2.47	3.28
	General chemistry	13	16.05	21.31
	Structural chemistry	7	8.64	11.48
	Analytic chemistry	5	6.17	8.20
	Environmental chemistry	3	3.70	4.92
	Thermodynamic and kinetics	3	3.70	4.92
	Inorganic chemistry	2	2.47	3.28
	Research	13	16.05	21.31
	Technology	6	7.41	9.84
	Citizenship and Inclusion	2	2.47	3.28
RQ3. Which strategies are currently being employed in chemistry and biology education?	Descriptive	30	37.04	58.82
	Relational	2	2.47	3.92
	Experimental	14	17.28	27.45
	Qualitative	30	37.04	58.82
RQ4. Which tools contribute to the efficacy of the teaching-researching process in chemistry and biology?	Virtual learning environments	13	16.05	18.57
	Simulations and virtual laboratories	12	14.81	17.14
	Interactive and visualization platforms	7	8.64	10.00
	Formative evaluation tools	27	33.33	38.57
	Communication and collaboration platforms	8	9.88	11.43
	Study design and development	2	2.47	2.86
	Data collection	60	74.07	85.71
	Data processing	5	6.17	7.14
	Data analysis tools	14	17.28	20.00

state of research in chemistry and biology education, offering insights and directions for future investigations.

The findings of this SLR carry significant implications for both future educational practice and research endeavors. For educational practitioners, the consistent emphasis on visual learning preferences in chemistry education suggests a practical path for enhancing pedagogical approaches. Implementing visual aids, such as diagrams and animations, can potentially improve comprehension and knowledge retention. However, the recognition of a minority preference for tactile learning underscores the importance of adopting multimodal strategies that cater to diverse learning styles. Educators are encouraged to embrace inclusive pedagogies that incorporate both visual and hands-on elements, promoting a comprehensive and adaptable learning environment.

Furthermore, regarding future research, the identified discrepancy in learning preferences highlights the need for more nuanced investigations into the dynamics of tactile learning in chemistry education. Exploring the effectiveness of hands-on experiences and tactile approaches could provide valuable insights for designing inclusive instructional strategies. Additionally, the synthesis underscores the significance of context-specific considerations in educational technology integration. Future research should delve deeper into the contextual factors influencing the impact of technology on student engagement, acknowledging the diversity of educational settings and their unique challenges.

6 Conclusion

The past five years have witnessed a transformative shift in research on chemical and biological education, challenging the conventional dominance of developed nations. Surprisingly, third-world countries, particularly Indonesia, have emerged as major contributors, highlighting a global trend in educational research efforts. This period experienced a surge in publications from 2019 to 2021. The scope of the educational context considered in our review is broad, covering diverse studies involving prospective and high school teachers, along with students in chemistry and biology education. The even distribution of studies in both subjects, coupled with a focus on foundational courses, reflects a holistic approach to fostering scientific careers and cultivating positive relationships with science. Employed strategies in chemistry and biology education reveal a rich array of approaches, predominantly focusing on descriptive and qualitative research. Various frameworks, including PAR, URE, CURE, and project-based methodologies, are actively employed, emphasizing innovation and adapting to the evolving educational landscape. In terms of tools contributing to the efficacy of the teaching-researching process, a significant shift toward virtual learning environments is evident, accelerated by the pandemic. Platforms like EDMODO, Zoom, MS Teams, e-magazines, and YouTube play pivotal roles, enhancing the pedagogical aspect. Noteworthy is the integration of widely used software such as Python, R, and SPSS, underscoring the importance of data management in educational scenarios.

This work reveals that research in chemistry and biology education has undergone a notable shift in recent years, highlighting the diversity of essential strategies, tools, and competence. There is a growing interest in the integration of sustainable approaches and an emphasis on developing research skills for both students and educators. The trend towards the application of digital tools and virtual environments is also noteworthy, showcasing significant adaptation in response to the COVID-19 pandemic. Additionally, the promotion of cognitive, social, and emotional competence emerges as a key aspect in education. The SLR thus serves as a valuable resource in delineating the multifaceted skills essential for fostering holistic development in both educators and students.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MA: Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. BVV: Data curation, Methodology, Software, Validation, Writing – original draft, Writing – review & editing. BEV: Data curation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. PF: Conceptualization, Data curation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This project received partial financial support from the Universidad Nacional de Chimborazo (UNACH).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1363132/full#supplementary-material

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