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Systematic literature review on the application of Problem-Based Learning model in chemistry education

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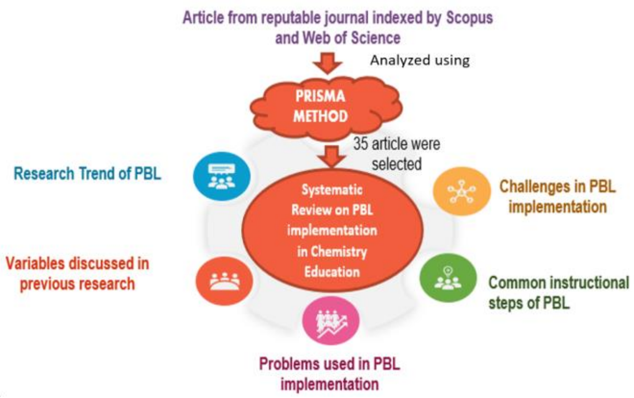
Abstract

Problem-based learning (PBL) has seen significant growth in recent years, but its effective implementation remains a challenge. Therefore, this study undertakes a systematic literature review to synthesise the research patterns, challenges, and approaches employed in chemistry education. PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analysis) methodology was employed in analysing publications within journals indexed in Scopus and Web of Science. A total of 523 papers have been found using some keywords. Following a thorough assessment, 35 publications were selected for in-depth analysis. The study found that PBL implementation varies depending on four primary variables: thinking skills, problem-solving abilities, conceptual comprehension, and argumentation skills. PBL concerns include issues like malnutrition, obesity, waste management, climate change, pollution, and green chemistry. Common instructional steps of PBL include problem orientation, student organisation, independent study, group investigation, reporting, and evaluation. Several challenges were found in applying PBL, including time limitation, instructor proficiency, student characteristics, and technical implementation of PBL. These findings are expected to complement the references for future research on PBL.



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Highlights

- Describe the trends of PBL research in the period 2013-2023.
- Analysing the common steps of PBL used by researchers in the period 2013-2023.
- Exposing the problems that were addressed by previous researchers applying PBL.
- Explain the challenges in using PBL in learning chemistry.

Contents

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1. Introduction

Chemistry is one of the branches of natural science that studies the structure, composition, properties, and changes of matter and the reactions accompanying the changes (Chang, 2010; Jespersen *et al.*, 2012). Everyday items such as foods, medicines, and cosmetics are practical manifestations of the applications derived from chemistry principles (Rusmansyah *et al.*, 2019). It is believed that through the study of chemistry, people can be trained to solve complex real-life problems. While learning chemistry poses challenges for students (Yerimadesi *et al.*, 2023), teaching chemistry at the school level fosters meaningful learning experiences that empower students to apply their knowledge in addressing everyday problems. The learning approach to fostering such meaningful learning is Student-Centred Learning (SCL).

SCL has garnered significant attention from educators in Indonesia and globally (Kaput, 2018). Recognising its pivotal role, educators across diverse nations acknowledge the significance of SCL in actively engaging students throughout the learning process (Estes, 2004). This approach not only fosters problem-solving, collaboration, and the development of critical thinking skills (Brush, 2000) but also brings enjoyment and sparks interest among students in their studies (Chairam *et al.*, 2015; Murni *et al.*, 2022). The approach is also considered effective in enhancing students' learning outcomes.

Problem-based learning (PBL) is one of the learning models encompassed within the framework of student-centred learning (SCL) (Ediansyah *et al.*, 2019; Ernawati *et al.*, 2022; Naji *et al.*, 2020). PBL uses complex real-world problems to encourage students to identify essential ideas in planning the problem solution (Flynn and Biggs, 2012), to train students in solving the problems given by the teacher and to find the optimal solution (Silver-Hmelo, 2004; Simamora *et al.*, 2017). Rooted in the constructivist learning theory, PBL facilitates the development of students' thinking skills through analysing real-life problems during the learning process (Abdullah and Panai, 2022). The students are provided with an ill-structured problem that they must solve, which becomes the starting point for them to obtain and integrate new knowledge.

Previous studies have revealed the positive impact of PBL on various educational facets, including enhanced learning outcomes, improved thinking ability, elevated problem-solving skills, strengthened argumentation skills and increased conceptual understanding. However, some studies on PBL reported that the learning model still cannot be applied optimally in the classroom, especially in learning chemistry. Teachers faced challenges in implementing PBL, with key problems revolving around constraints such as limited time for PBL implementation (Ayyildiz and Tarhan, 2018; Ernawati, 2021; Ernawati *et al.*, 2022; Hugerat *et al.*, 2021; Kartamiharja *et al.*, 2020; Seçgin and Sungur, 2021). Additionally, other challenges were identified, including teachers lacking proficiency in using PBL, student characteristics affected the learning process (Ayyildiz and Tarhan, 2018; Seçgin and Sungur, 2021; Tosun and Taskesenligil, 2013), and teachers challenges in supporting PBL implementation (Batdi, 2014). Consequently, these obstacles hinder the attainment of learning objectives. Therefore, a Systematic Literature Review (SLR) on PBL is necessary to provide an overview of how the previous researchers have implemented PBL and the obstacles encountered in the process.

Previous researchers have conducted SLR on PBL within various fields. Noteworthy examples of these SLRs include the study of the effectiveness of PBL in developing critical thinking skills of nursing students (Kong and Qin, 2014), PBL's role in mathematics learning (Merritt *et al.*, 2017), trends in PBL models within university science courses (Azhar *et al.*, 2023), PBL assessment in medical schools (Nendaz and Tekian, 1999), the effect of PBL during medical school on physician competence (Koh *et al.*, 2008), and bibliometric analyses on the implementation of PBL models in science education (Nurhayati *et al.*, 2023).

However, our search did not find any SLRs specifically addressing the implementation of PBL in chemistry education. Consequently, a systematic, step-by-step review is needed to explore the trend and applications of PBL in chemistry education over the past decade. This review aims to provide readers and prospective researchers with insights into PBL research trends in chemistry education, highlighting variables that have received much attention, issues raised by PBL, common PBL procedures employed by previous researchers, and challenges encountered during PBL implementation. This SLR intends to provide necessary information for future researchers interested in implementing PBL in science or chemistry classrooms, enabling them to consider the weaknesses and obstacles identified by prior researchers in their future endeavours.

1.1. Research aim

The primary objective of this SLR is to review, examine, and draw comparisons among prior studies that have used PBL models in science education, with particular emphasis on chemistry education. This review encompasses studies published in reputable journals indexed by Scopus and Web of Science during the period from 2013 to 2023. Serving as an initial point of reference, this SLR is intended to be a valuable resource for future researchers keen on exploring and applying PBL to their work. The result of our study aims to provide insights into the historical implementation of PBL and the challenges encountered. By doing so, we hope to assist future researchers in anticipating these challenges, thereby optimising the outcomes of their research endeavours.

1.2. Research question

This review is oriented towards addressing the following research questions:

RQ 1. What characterizes the research trends of PBL application in chemistry education from 2013–2023?

RQ 2. Which variables have been studied by researchers in the exploration of PBL within the past studies?

RQ 3. How is the context of the problem discussed in PBL learning described in previous studies?

RQ 4. What are the common steps of PBL implemented in chemistry learning within the past studies?

RQ 5. What challenges have previous researchers encountered when applying PBL in chemistry education?

2. Experimental

This research is characterized as a Systematic Literature Review (SLR), which is an investigative approach that systematically, clearly, and comprehensively synthesizes prior research findings, allowing for replicability (Snyder, 2019; Xiao and Watson, 2019). Employing a method that is both systematic and transparent in addressing research questions, SLR can provide a brief overview of the scientific topics under consideration (Kurniati *et al.*, 2022; van Dinter *et al.*, 2021). This study aims to identify and analyse various articles on PBL engaging in an in-depth examination of 35 articles that align with predefined criteria.

The review and analysis of articles in this study used the PRISMA model (Preferred Reporting Items for Systematic Review and Meta-Analysis). PRISMA is a tool and guide for evaluating systematic reviews and meta-analyses (Zarate *et al.*, 2022).

In this study, the authors chose to use the PRISMA model because PRISMA has a clear and structured framework at each research stage. Adopting the PRISMA model is advantageous as it facilitates the effective synthesis of articles meeting the criteria while mitigating potential biases that may arise during the study (Moher *et al.*, 2009; 2010). In addition, PRISMA also encourages authors to report every step of their research in detail. This allows other researchers to replicate our research and verify the results obtained, thus increasing the credibility and quality of the research results. The PRISMA model consists of several processes, including identification, screening, eligibility, and quality assessment of articles.

2.1. Identification

Identification is finding, considering, and diversifying appropriate keywords for article searches. This keyword assignment was done before the literature search so that the resulting articles would be more accurate and aligned with the desired topic. The phrases "problem-based learning, science learning, PBL effectiveness, and PBL implementation" were used as keywords to search articles in the Scopus, ERIC, and Publish or Perish 8 databases to obtain reputable articles indexed by Scopus and Web of Science. The identification of keywords for this research is described in **Table 1**.

Table 1. Keywords search of articles in the database.

Database	Keyword
Scopus by ERIC	"Problem-based learning*" OR "PBL*" AND "Science Learning" AND "PBL effectiveness*" OR "Implementation of PBL" AND "PBL in chemistry"
Scopus by Publish or Perish 8	TITLE-ABS-KEY (("problem-based learning*" OR "PBL*") AND PUBYEAR > 2013 AND PUBYEAR < 2023 AND LIMIT-TO (SUBJAREA, "SOCI") AND LIMIT-TO (DOCTYPE, "ar") AND (LIMIT-TO (EXACTKEYWORD, "Chemistry learning") OR LIMIT-TO (EXACTKEYWORD, "Implementation of PBL") OR LIMIT-TO (EXACTKEYWORD, "PBL Effectiveness*") OR LIMIT-TO (EXACTKEYWORD, "Science Learning")) AND LIMIT-TO (LANGUAGE, "English")
Web of Science	TS = (("Problem based learning*" OR "PBL*") AND "Science Learning" AND ("PBL effectiveness*" OR "Implementation of PBL" OR "PBL in chemistry"))

Source: Elaborated by the authors.
Notes: **AND / OR** are Boolean operators used to combine keywords logically; ***represents a wildcard**, including different word endings (e.g., "learning*" covers "learning", "learned", "learners" etc.); **TITLE-ABS-KEY** searches within the **title**, **abstract**, and **keywords** fields in Scopus; The **Scopus (via PoP 8)** search uses advanced filters: publication year, subject area, document type, language, and specific keywords.

The search terms outlined in **Table 1** resulted in the identification of 523 articles. Among these, 369 articles were in the ERIC database, 130 in the Scopus database using Publish or Perish 8, and 24 in Web of Science. The search parameters were limited to articles published within the last ten years. The literature search in this study was conducted in March 2023, meaning that the articles included in the criteria of this study were Scopus and Web of Science-indexed articles published from January 2013 to March 2023. Scopus and Web of Science were chosen as the primary databases for determining the inclusion criteria in this study due to their several advantages. Firstly, Scopus and Web of Science offer search results that are more stable, functional, and comprehensive compared to others (Gusenbauer and Haddaway, 2021). In addition, the articles indexed by Scopus and Web of Science demonstrate higher quality due to their emphasis on quality control and a systematic indexing system (Martín-Martín *et al.*, 2018). The better the quality of a paper, the more it will be cited by other researchers (Nugroho, 2022). Therefore, papers published in Scopus-indexed journals and Web of Science are more likely to be cited (Schafmeister, 2021), thereby enhancing the author's prestige.

2.2. Screening

The process of determining the inclusion and exclusion criteria of the articles studied to form a systematic literature review is carried out in this screening stage (Mohamed Shaffril *et al.*, 2020). Before the screening, the researchers excluded five duplicate articles from the initial 523 articles gathered in the previous stage. The screening process was applied to the remaining 518 articles obtained during the identification stage, employing various inclusion criteria. The first criterion was the year of publication, with inclusion limited to articles published in the last ten years, from 2013 to 2023. The study will likely include the most recent articles within this period to describe the trend of PBL research in science education, especially chemistry.

The second criterion considered when selecting articles is publication type. In this study, only articles from reputable journals were considered. Such articles are deemed of higher quality, having undergone a rigorous review process before publication. Furthermore, the study exclusively includes research articles based on empirical data. This criterion was pivotal in selecting articles, with proceedings, book chapters, and review articles excluded from the collected data as they did not meet these specified criteria.

The next criterion considered in the data selection is the language employed in the article. The analysis was restricted to articles written in English. This measure is implemented to mitigate potential errors in transcription and comprehension of the article's content, ensuring clarity in delivering reviews associated with the studied articles. The final criterion is focused on thematic relevance, specifically examining articles related to PBL in science or chemistry education, implementation of PBL, effectiveness of PBL, and description of PBL steps taken. For a more detailed overview, the inclusion criteria for the articles selected are outlined in **Table 2**.

Following the screening process according to the inclusion criteria outlined in **Table 2**, 419 articles were deemed ineligible and excluded. Subsequently, the remaining 99 articles underwent the eligibility assessment for inclusion in this study.

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Table 2. Inclusion criteria of the articles.

Category	Inclusion Criteria
Publication year	Januari 2013-March 2023
Publication type	Journal articles only
Language	English
Type of Finding	Research based on empirical data
Focus of finding	Data related to PBL in science or chemistry education, Implementation of PBL, effectiveness of PBL, instructional steps of PBL in previous research

Source: Elaborated by the authors.

2.3. Eligibility

The eligibility stage aims to identify articles that align closely with the study objectives, ensuring that the selected articles make substantive contributions to the study. The second stage of the screening (the eligibility stage) is carried out by analysing the abstract, title, methodology, research outcomes, and discussion of the remaining 99 articles. An evaluation was then conducted to determine whether the articles were consistent with the subject matter of the ongoing study. During this process, 64 articles were excluded for various reasons, including the research type being qualitative or classified as research & development (R&D). This is because both types of research (qualitative and R&D) are often conducted on a small scale and in a particular context. They also provide in-depth qualitative data about a process. In contrast, SLR requires research with larger and diverse samples with quantitative data that can be generalised from multiple studies to infer broadly applicable trends or patterns.

This study exclusively analysed articles falling within experimental, mixed-methods, and action research categories. The primary aim is to identify how PBL is implemented in chemistry education based on previous studies and to investigate challenges encountered during the implementation of PBL. Articles that are not based on empirical data were excluded from consideration. Articles discussing PBL in medical, social, language, and art fields were excluded from the study. The review focused solely on articles addressing PBL in science and chemistry, given that science falls within the same scientific cluster as chemistry, the main subject of this study. Consequently, the instructional steps related to PBL identified in these articles can be inferred and applied to the context of chemistry education. Furthermore, articles lacking discussion on implementing PBL in their research were excluded, as they were considered to require more detailed information. Following the eligibility process, 35 articles remained for further analysis in the subsequent quality assessment stage. The systematic literature review process is illustrated in **Fig. 1**.

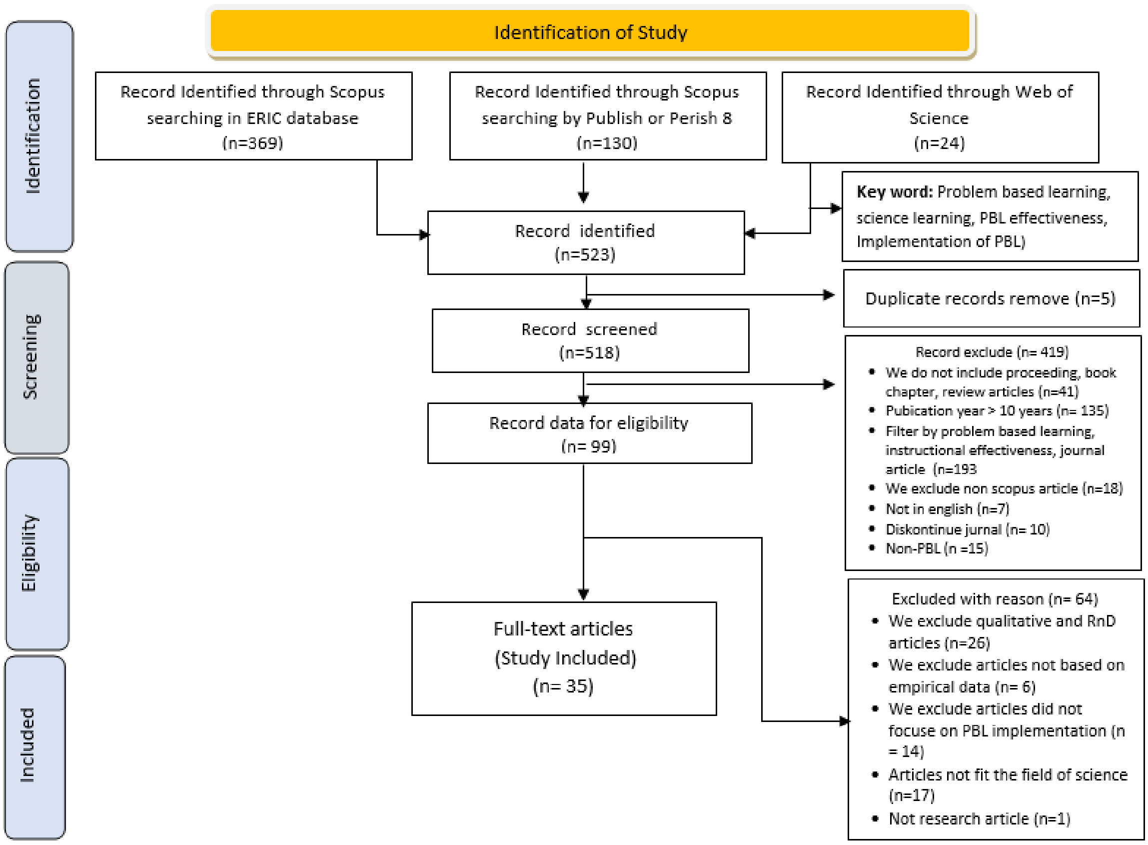

Figure 1. Systematic literature review flowchart using the PRISMA model.
Source: Elaborated by the authors.

2.4. Quality assessment

To ensure the quality of the articles selected for study and to mitigate potential biases in the research outcomes, the remaining 35 articles were evaluated by two raters who were PhD students in chemistry education. In this context, the two raters were tasked with categorising the articles based on the methodology into three quality tiers: high, medium, and low (Petticrew, 2008). The parameters used in this assessment included research design, research sample, research instruments, research procedures and data analysis. Only articles categorized as high and medium quality were considered for inclusion in the research.

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Furthermore, consensus between the two raters was crucial, demanding an agreement that the selected articles must possess at least medium quality. In the event of discordance between the raters, any differences were resolved through in-depth discussion before deciding to include or exclude the article from the study.

The evaluations conducted by the two raters were subsequently subjected to analysis using SPSS 27 to compute the kappa agreement value (k). Based on the SPSS 27 calculation, as illustrated in **Fig. 2**, the resulting kappa value is 0.723. This value signifies that the strength of agreement between raters in this study falls within the "good" category. Through this assessment process, 18 articles were rated as high quality, while 17 articles were rated as medium quality by both raters. Thus, all the remaining articles were deemed eligible for further analysis in this study.

Symmetric Measures

		Value	Asymptotic Standard Error[a]	Approximate T[b]	Approximate Significance
Measure of Agreement	Kappa	.723	.110	4.511	<.001
N of Valid Cases		35			

a. Not assuming the null hypothesis.

b. Using the asymptotic standard error assuming the null hypothesis.

Figure 2. Kappa agreement value between two raters using SPSS 27.
Source: Elaborated by the authors.

2.5. Data extraction and analysis

Articles that successfully passed the quality evaluation stage were then further analysed to identify patterns that address the predetermined research question. This data analysis process involved carefully examining the 35 articles selected as research objects, wherein data were extracted and organized into a table to facilitate the following analysis process. This SLR focuses on identifying research trends related to PBL, reviewing prior research findings on PBL in science/chemistry education to obtain common PBL steps, analysing the contextual aspects of PBL problems employed, and analysing the challenges encountered by previous researchers during the PBL implementation. To address these objectives, the data extraction process focused on the three main components of each article: the abstract, results, and discussion.

Several data analysis tools were utilized by the authors, including Mendeley Reference Manager, VOS Viewer, and MS Excel. The complete article that became the object of research was downloaded and uploaded to Mendeley. Subsequently, Mendeley files are exported in ".ris" format, so they can be exported to the VOS Viewer application to illustrate PBL research trends in terms of publication year data, authors, keywords, and variables used in previous studies. Simultaneously, MS Excel was utilized to present the data through graphs and tables, enhancing comprehension and interpretation.

2.6. Information on Artificial Intelligence (AI) Tools

This article was written using artificial intelligence tools like Quilbot for paraphrasing, Grammarly for improving sentence structure, and Turnitin for detecting plagiarism.

3. Results and discussion

3.1. Research trend of PBL application in chemistry education

Concerning the categorization of journals, the 35 articles under examination in this study exhibit a distribution across various tiers: 11 articles published in Scopus Q1 journals, 12 articles published in Scopus Q2 journals, five articles published in Scopus Q3 journals, two articles published in Scopus Q4, and the remaining five articles published in a journal indexed by Web of Science (WoS). This distribution implies that most of the studies reported in these journals are considered reputable. Furthermore, the articles were analyzed and classified based on the following categories to distinguish the research trend related to the implementation of PBL in chemistry education.

3.1.1. Distribution year

Figure 3 illustrates the annual publication trends of articles on Problem-Based Learning (PBL) in chemistry education from 2013 to 2023.

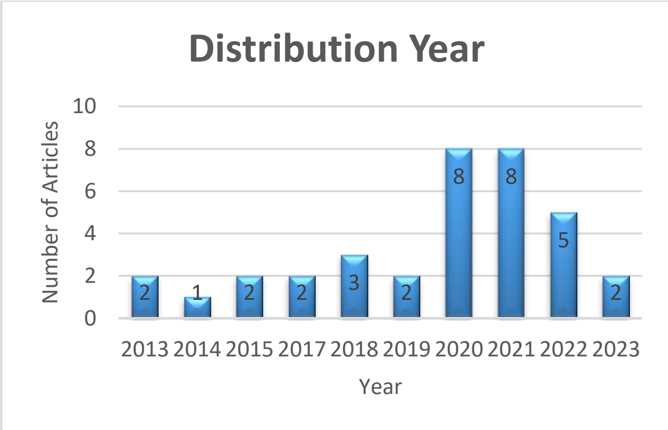

Figure 3. Research distribution by publication year.
Source: Elaborated by the authors.

Based on **Fig. 3**, the number of publications on implementing Problem-Based Learning in chemistry education has fluctuated over the past decade. This aligns with findings from earlier studies that indicate an increasing trend in the number of PBL research articles in chemistry education between 2013 to 2018 (Nurhayati *et al.*, 2023). The average number of articles addressing the theme of PBL in science learning published per year was 2 from 2013 to 2018.

The results of our study reveal that the peak of PBL publications occurred in 2020 and 2021, with both years showcasing the publication of 8 PBL articles in the field of education, featured in reputable journals. In 2022 and 2023, there was a decrease in the number of publications with PBL topics published in similar journals, although additional data for 2023 may be imminent. It is noteworthy that, at the time of data collection in March 2023, there remains a nine-month window until the end of 2023, allowing for the potential emergence of more publications on the topic of PBL implementation in science and chemistry education within other reputable journals.

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Moreover, several studies underline the potential for future research on PBL, highlighting its relevance and capacity for promoting 21st-century skills (Azhar *et al.*, 2023; Rahayu, 2017). These skills are fundamental in preparing students to face the challenges of the ever-changing modern world (Ayyildiz and Tarhan, 2018; Roza *et al.*, 2023; Sudarmin *et al.*, 2019). The ongoing global changes across various domains aim to enhance the quality of life in modern societies. Consequently, there is a growing focus among educators, educational institutions, and stakeholders on incorporating efforts to infuse 21st-century skills into the learning process. Universities recognize the importance of producing graduates who are academically intelligent and ready to navigate real-world challenges. By providing inclusive education centred on 21st-century skills, students stand a greater chance of success in the future and can contribute to the diversity and complexity of the global society (Zubaidah, 2020).

3.1.2. Geographical distribution

Concerning the geographical distribution of research on PBL in chemistry education, investigations have taken place in various countries worldwide, including Indonesia, Turkey, the USA, Australia, Spain, the Philippines, India, and South Korea, as illustrated in **Fig. 4**. Notably, Indonesia and Turkey are prominent contributors to PBL research, constituting 37.14 and 31.4% of the 35 articles examined in this study. Additionally, 14.29% of the research was conducted in the USA, while the remaining 17.17% was distributed across India, the Philippines, South Korea, Israel, and Spain. This distribution differs from the findings of Samosir *et al.* (2023), who focused on PBL research at the junior high school level and identified the United States as the leading country in applying PBL in that educational context.

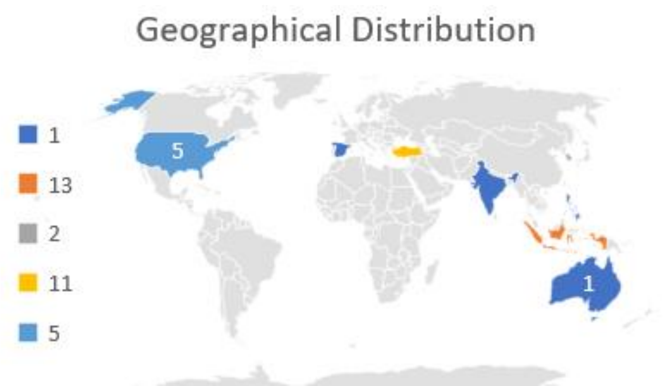

Figure 4. Distribution of studies across countries.
Source: Elaborated by the authors.

Further analysis reveals the distribution of PBL research implementation in terms of continents, as depicted in **Fig. 5**. Within this categorization, the Asian continent takes the lead, contributing more than half (65.71%) of the articles reviewed in this study. Europe follows with the second-highest representation at 17.14%, followed by the Americas, accounting for 14.29% of the total articles examined. Notably, there is an absence of PBL articles or research in science and chemistry education on the African continent and oceanic countries, marking an interesting aspect of this data.

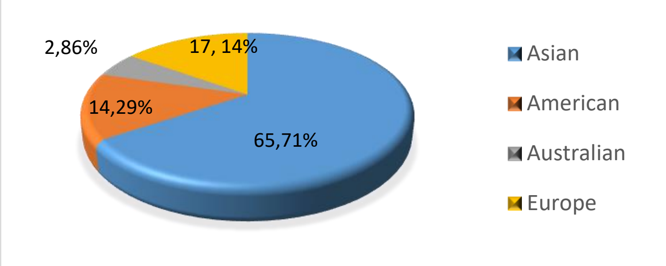

Figure 5. Distribution of research across the continent.
Source: Elaborated by the authors.

3.1.3. Distribution by educational level

Figure 6 illustrates that most of the research on implementing PBL in science and chemistry education was conducted at the university and senior high school levels. Based on the analysis of the article, most of the studies, encompassing 16 articles (45.71%) out of 35 papers, were conducted at the university level. Meanwhile, PBL research at the senior high school level ranked second with 37.14%. The PBL model suits senior high school and college students (Yin Peen and Yusof Arshad, 2014). Notably, PBL implementation requires students to be independent in solving problems through individual and group learning.

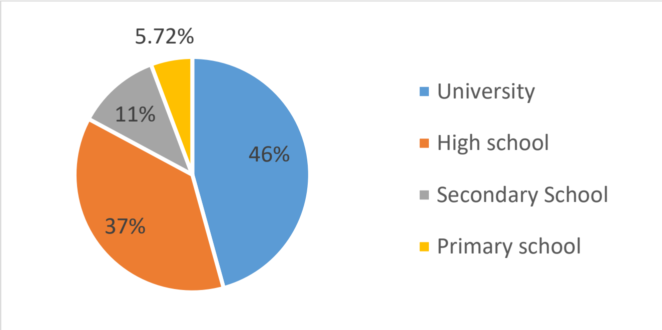

Figure 6. Distribution of research across educational levels.
Source: Elaborated by the authors.

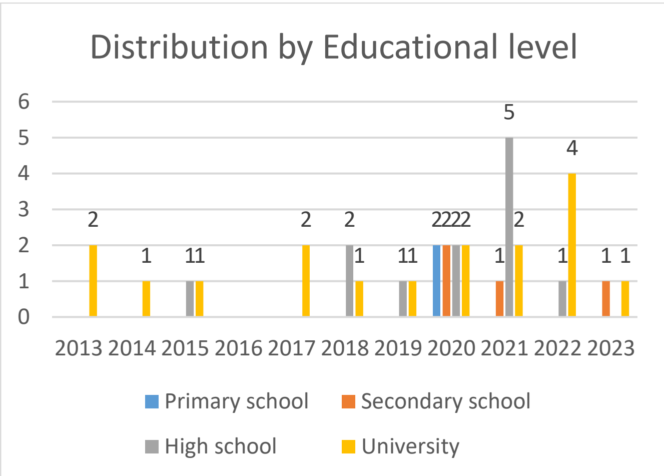

Figure 7. Distribution of research by educational level annually.
Source: Elaborated by the authors.

On the other hand, PBL at the junior high school level was discussed in only four articles (11.43%). An intriguing finding from this review is that researchers have explored the application of PBL learning to elementary school students. Even though elementary school students may not possess complete independence in learning, requiring guidance from the teacher as a facilitator, there are limited studies on PBL at the primary school level (Wandira *et al.*, 2023). Therefore, implementing PBL models in primary schools may present an opportunity for future PBL research.

The distribution of PBL research based on the educational level of the participants per year is depicted in **Fig. 7**. The figure illustrates that, over the years, PBL research on senior high school and university students has been dominant. This result is consistent with the study by Azhar *et al.* (2023), which concluded that PBL application in higher education is more prevalent and successful in enhancing students' 21st-century skills. In concurrence, Roza *et al.* (2023) revealed that the PBL approach was effectively implemented in teaching biology, chemistry, and other science subjects at the college level.

The peak of PBL research occurred in 2020 and 2021 when researchers were able to publish eight PBL-related articles per year. However, there was a decline in 2023 as our data collection only extended until March 2023.

3.1.4. Research methods used in previous PBL implementation

Patterns in the research methodologies on PBL application in science, especially chemistry education, as published in reputable international journals, are outlined in **Table 3**.

Table 3. Distribution of research-by-research methods.

Research Methods	n	P (%)	References		
Quantitative	20	57.14	Akhdinirwanto *et al.* (2020) Ayyildiz and Tarhan (2018) Batlolona and Souisa (2020) Cahyono *et al.* (2021) Ernawati (2021) Günter *et al.* (2017) Hugerat *et al.* (2021)	Jumadi *et al.* (2021) Kuvac and Koc (2019) Marthaliakirana *et al.* (2022) Palupi *et al.* (2020) Rehmat and Hartley (2020) Seçgin and Sungur (2021) Simanjuntak *et al.* (2021)	Tosun and Senocak (2013) Tosun and Taskesenligil (2013) Ulger (2018) Valdez and Bungihan (2019) Yoon *et al.* (2014)
Qualitative	2	5.72	Kim *et al.* (2019)	Varadarajan and Ladage (2022)	
Mix-methods	10	28.57	Aslan and Duruhan (2021) Baran and Sozbilir (2018)	Costa *et al.* (2023) Kartamiharja *et al.* (2020)	Kim *et al.* (2022) Liu *et al.* (2018) Ramlo *et al.* (2021)
Action research	3	8.57	Laksmi *et.al.* (2021)	Overton and Randles (2015)	Pritasari *et al.* (2015)

Source: Elaborated by the authors.

Table 3 shows that the quantitative method is the most used research methodology across the 35 articles under study. Quantitative research methods constitute 57.14% of the total object study. Almost 90% of the total quantitative research identified was experimental research. This indicates that over half of the investigations in the examined papers used experimental methods for data collection. This outcome is consistent with the findings of Azhar *et al.* (2023), who asserted that the experimental method is the most popular in the PBL application at the university level. Experimental research holds broader usage than other methodologies in educational and learning research. Typically, experimental research aims to assess the impact of implementing the PBL model in science education on variables related to 21st-century skills, including critical thinking (Cahyono *et al.*, 2021; Marthaliakirana *et al.*, 2022), creative thinking (Nuswowati *et al.*, 2017; Simanjuntak *et al.*, 2021; Yoon *et al.*, 2014), problem-solving (Tosun and Taskesenligil, 2013), scientific argumentation (Akhdinirwanto *et al.*, 2020; Cahyono *et al.*, 2021), metacognitive awareness (Tosun and Senocak, 2013) and others.

Meanwhile, mixed methods constitute the second-highest percentage at 28.57%. This approach combines qualitative and quantitative methodologies within a study (Creswell and Clark, 2018), enabling the collection and analysis of both data types to provide an understanding of a phenomenon (Halcomb and Hickman, 2015). Researchers employing mixed-method studies are not restricted to a singular research approach or data type; rather, they must integrate quantitative and qualitative methods to explore diverse aspects comprehensively. The research examined the impact of PBL supported by Augmented Reality (AR) on improving reflective thinking for problem-solving skills (Arici and Yilmaz, 2023), the influence of the PBL model with scaffolding on students' creative thinking skills and their response to scaffolding in PBL (Ernawati, 2021), and the effectiveness of PBL in chemistry education concerning tofu wastewater treatment (Kartamiharja *et al.*, 2020). In 2021, a study was conducted to investigate the influence of problem contexts on students' creative thinking skills (Ernawati, 2021), while another study investigated the PBL influence on context on student achievement, knowledge retention, motivation (Hugerat *et al.*, 2021), and attitudes towards chemistry, as reported by Baran and Sozbilir (2018).

Moreover, Hugerat *et al.* (2021) explored the impact of PBL combined with Jigsaw Discussion (PBL-JD) on student motivation in learning science. Ramlo *et al.* (2021) examined students' perspectives on PBL-based chemistry laboratories in science courses. Liu *et al.* (2018) investigated the effects of PBL learning environments enriched with multimedia on students' science knowledge by administering pretests and post-tests before and after learning. The outcomes of the mixed-method research in this review suggest a favourable inclination towards utilizing PBL for chemistry education to enhance learning achievement and life skills among students, following the requirements of modern education.

Qualitative research methods were the least popular in this review, each accounting for 5.72% of the total. The lack of qualitative studies is attributed to the eligibility stage, where qualitative methods were considered ineligible for the study's objectives. The focus was on assessing PBL implementation, the process of learning chemistry with PBL, and its impact on the observed variables. Thus, most of the PBL qualitative studies in the sample were excluded based on the criteria set for this study.

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3.2. Variables studied by PBL researchers

The identification of frequently occurring keywords in the articles examined in this study was conducted utilising the Mendeley Reference Manager and VOS Viewer tools. Article data that has been downloaded is stored in Mendeley and then exported in RIS* format. Afterwards, the file is imported into the VOS viewer, and keyword analysis is carried out. VOS viewers display for the analysis type "co-occurrence--> keywords" analysis type (Fig. 8) reveal four primary keywords that previous researchers commonly used in articles addressing "the implementation of PBL in learning science". The four themes are indicated by large circles in the VOS Viewer visualization. The identified keywords are problem-based learning, problem-solving skills, argumentation skills, and cooperative learning. When the keyword problem-based learning is designated as the main keyword, the VOS viewer visualisation transforms, as shown in Fig. 9. The keyword problem-based learning frequently appears and demonstrates a connection to other keywords such as motivation, creative thinking, argumentation, and problem-solving skills.

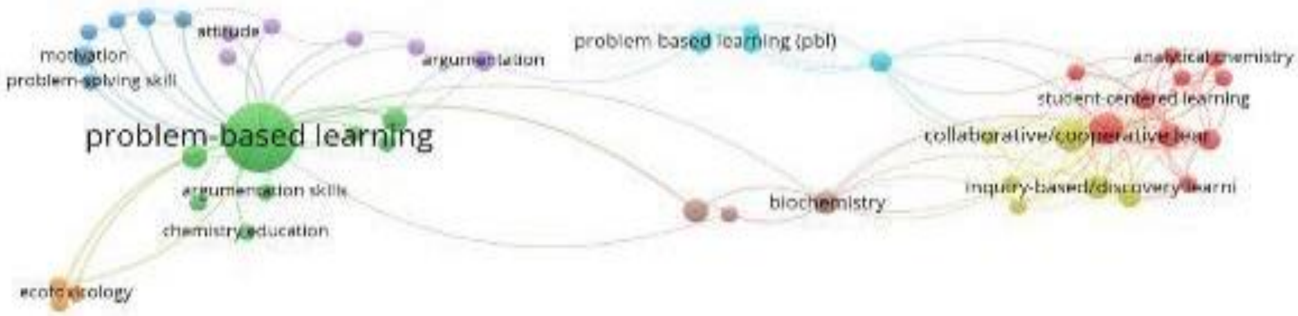

Figure 8. VOS Viewer presentation for the type of analysis "Co-occurrence--> keywords".
Source: Elaborated by the authors.

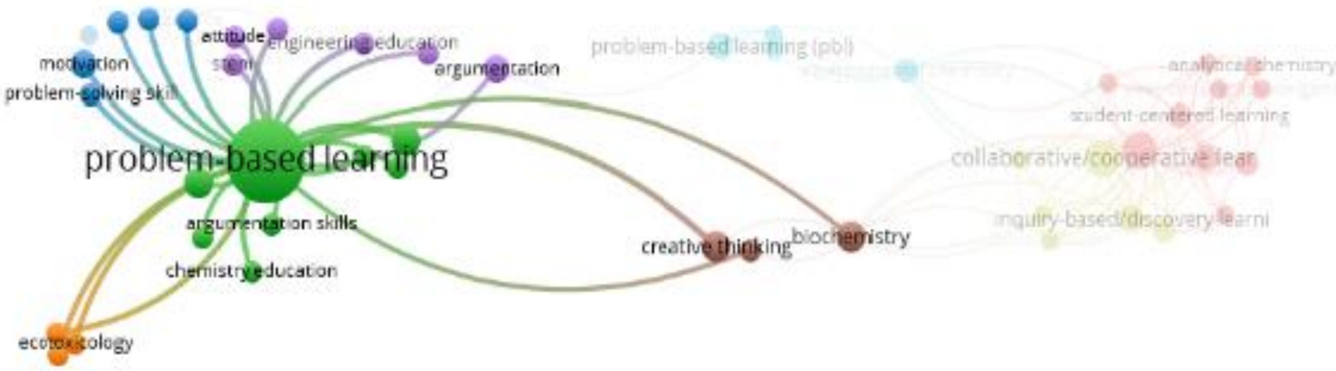

Figure 9. VOS Viewer presentation for the type of analysis "co-occurrence-->keywords: problem-based learning".
Source: Elaborated by the authors.

Apart from utilising the VOS Viewer tool, we also conducted an in-depth analysis of the articles by inputting data from the articles into analysis tables tailored to the study's requirements. The outcomes of the analysis of variables commonly employed by previous researchers are shown in Table 4. Thinking ability emerges as a frequently used variable, with a prevalence of 20.48%. Subsequently, problem-solving skills (9.64%), argumentation skills (8.43%), conceptual understanding (8.43%), and various other variables are also frequently employed by researchers in PBL studies.

Table 4. Distribution of variables used in PBL.

Variable	Frequency	%
Thinking skills	17	20.48
Problem-solving skill	8	9.64
Argumentation skill	7	8.43
Conceptual understanding	7	8.43
Learning achievement	6	7.23
Scaffolding	6	7.23
Motivation	6	7.23
Scientific behaviours	6	7.23
Metacognitive awareness	4	4.83
Students' knowledge	3	3.61
Self-regulated learning	3	3.61
Academic background	3	3.61
Decision making	3	3.61
Age, gender	2	2.41
Scientific process skill	1	1.21
Information literacy	1	1.21

Source: Elaborated by the authors.

3.3. Problems in PBL discussed by previous researchers

The problems used in PBL learning are usually related to students' daily lives. The article analysis results showed that not all articles studied explained the kinds of problems raised by educators when implementing problem-based learning (PBL) models in science learning, especially chemistry. Table 5 presents some issues that can be recorded from analysing the articles on the research object.

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According to Table 5, PBL has been applied in science education in various fields, including general science, biology, physics, chemistry, and its subfields, such as organic chemistry, analytical chemistry, environmental chemistry, and biochemistry. PBL learning is mainly concerned with problems students commonly face daily. Incorporating authentic, real-world problems into chemistry learning is crucial in fostering students' skill development and affective growth (Rahayu, 2019). Based on the reviews, examples of problem scenarios employed for PBL-based chemistry instruction are health issues like malnutrition and obesity (Marthaliakirana *et al.*, 2022); waste management (Yoon *et al.*, 2014), (Varadarajan and Ladage, 2022); environmental pollution (air, water, dan soil) (Kartamiharja *et al.*, 2020; Kuvac and Koc, 2019); climate change (Pritasari *et al.*, 2015); and Green chemistry and sustainability (Günter *et al.*, 2017). This finding aligns with the study (Qamariyah *et al.*, 2021), which states that chemistry is closely related to social problems such as global warming, pollution, nuclear power plants, additives in food and health problems. Therefore, for students to understand chemistry well, teachers must be able to design contextual and actual problems for students and connect them with the chemistry material being studied so that students are actively involved in each PBL step implemented.

Table 5. The problems context employed by previous researcher in PBL.

Level academic	Subject	Problems context
Elementary School	Science	Respiratory system and its disturbances (Palupi *et al.*, 2020) Natural disaster, Living things and their habitats (Rehmat and Hartley, 2020)
Junior High school	Science	Temperature and heat (Akhdinirwanto *et al.*, 2020) Force and Energy (Aslan and Duruhan, 2021)
Senior High School	Chemistry	Atomic structure, chemical bonding, Carbonic compound, organic compound, mol concept (Valdez and Bungihan, 2019) Enthalpy change in the system (Ayyildiz and Tarhan, 2018)
	Science	Environmental pollution, the environmental change/climate and waste recycling (Pritasari *et al.*, 2015)
	Biology	Environment (Laksmi *et al.*, 2021) Blood circulation system (Hugerat *et al.*, 2021)
University	Biochemistry	Amino Acid and protein (Ernawati, 2021; Ernawati *et al.*, 2022; Hugerat *et al.*, 2021) Mendel's law and genetics (Seçgin and Sungur, 2021)
	Environmental chemistry	Waste treatment (Varadarajan and Ladage, 2022) Tofu liquid waste treatment, river water pollution due to settlement waste (Kartamiharja *et al.*, 2020) Environmental problem, green chemistry (Nuswowati *et al.*, 2017) 'Ecosystems and Biodiversity'; Environment and Water'; 'Environment and Air'; 'Environment and Soil' and 'Environment and Energy' (Kuvac and Koc, 2019)
	Fundamental chemistry	Thermodynamic, high quality water resources, Analysis of heavy metal content in water and soil samples; Identification of organic compounds in petroleum samples; Analysis of nutrient content in sports food; Case studies of carbon monoxide gas poisoning (Baran and Sozbilir, 2018) Solution and its physical properties (Tosun and Senocak, 2013; Tosun and Taskesenligil, 2013) Air quality, Air pollution (Kim *et al.*, 2022)
	Analytical Chemistry lab	Green chemistry and sustainability (Günter *et al.*, 2017) Treatment of wastewater contaminated with acids and bases, Identification of metal and non-metal Ions (Yoon *et al.*, 2014)
	Physics	Temperature and heat (Batlolona and Souisa, 2020)
	Biology	Healthy diet, the benefits of food for health, cases of obesity, and malnutrition (Marthaliakirana *et al.*, 2022)
	Organic Chemistry	NMR spectroscopy data analysis, programming, and processing (Costa *et al.*, 2023)

Source: Elaborated by the authors.

3.4. Common instructional steps employed in applying PBL in chemistry learning

The article review was conducted to identify the steps of PBL implementation in chemistry learning in previous studies. Based on the results of this identification, we found several PBL steps carried out by past researchers, as presented in Appendix 1. Based on the PBL Steps that previous researchers have done, we found some common steps that must be present in the PBL model presented in Table 6. However, from the results of the analysis, it turns out that 28.57% of the articles that are the object of study do not explain explicitly or implicitly the PBL learning steps applied in their studies.

Based on these steps, the author concluded that the common steps of PBL performed by previous researchers consisted of six steps: problem orientation, student organizing, independent study, group investigation and group discussion, reporting and presenting the results, and evaluation and reflection. In PBL, students are involved in the problem-solving process by conducting investigations through the stages of the scientific method (Asmi *et al.*, 2019). Applying the PBL model, lecturers are no longer the only source of information; they also help students direct problems to learning by providing learning materials and resources (Munzil and Mentari, 2021). So, the stages of PBL provide opportunities for students to question existing phenomena and actively build an understanding of the concepts being studied.

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Table 6. Common step PBL conducted by previous researchers.

No	Common Step PBL	Activity
1	Problem orientation	a. Presenting ill ill-structured problem b. Generating ideas for questions c. Develop a problem scenario. d. Collect information needed for problem-solving. e. Consider potential solutions to solve the problem.
2	Students organizing	a. Forming heterogeneous small groups b. Determine the roles of group members.
3	Independent study	a. Out-of-class learning b. Assessing information from various learning sources, ex, mass media, social media, internet, articles, books, etc.
4	Group investigation and group discussion	a. Sharing information with group members b. Critically evaluate the resources and knowledge they have collected. c. Investigate to solve the problem. d. Data analysis
5	Reporting and presenting the results.	a. Making a group report b. Presenting the results of the discussion in front of the class c. Class discussion
6	Evaluation and reflection	a. Improve the group report according to teacher and audience suggestions b. Strengthening the concept

Source: Elaborated by the authors.

3.5. Challenges in using PBL in learning science/chemistry

Through analysing 35 articles that became the focus of our study, we found several challenges in implementing the PBL in the classroom. These challenges are related to time, teacher ability, student characteristics and technical implementation of PBL. Some of the obstacles include: First, the implementation of PBL in chemistry learning requires much time for lecturers or educators because they have to make careful preparations such as preparing issues/problem contexts related to the material being studied, preparing scaffolding to direct students before working and discussing in groups, and briefing students about the implementation of PBL learning that will be carried out (Ayyildiz and Tarhan, 2018; Ernawati, 2021; Ernawati *et al.*, 2022; Hugerat *et al.*, 2021; Kartamiharja *et al.*, 2020; Seçgin and Sungur, 2021). Time constraints like this can be reduced using media in PBL (Pertiwi *et al.*, 2021).

The second challenge that occurred during the implementation of PBL in previous studies was the class interruption caused by students who were still unfamiliar with the PBL model, so what the teacher and instructor planned did not run correctly (Ayyildiz and Tarhan, 2018; Seçgin and Sungur, 2021; Tosun and Taskesenligil, 2013). Students also do not understand their role and the role of the lecturer in PBL (Ayyildiz and Tarhan, 2018). Therefore, teachers should socialize the PBL model and explain students' tasks and roles in PBL before implementing this model. The third challenge is the limited skills of teachers in implementing PBL in learning, so the expected improvement in students' skills is not very significant (Ayyildiz and Tarhan, 2018; Kim *et al.*, 2019; Marthaliakirana *et al.*, 2022).

The unequal distribution of tasks among group members is the fourth challenge in implementing PBL. This causes one group member to dominate the activity while the other members become only followers, while the assessment given is the same for both passive and active group members (Baran and Sozbilir, 2018). Fifth, the emergence of alternative conceptions is caused by students' failure to connect or integrate their prior knowledge with the new concepts they are learning (Ayyildiz and Tarhan, 2018). Therefore, teachers must create situations that can activate their students' prior knowledge to change their mindset from remembering information to a meaningful learning process (Gazali and Yusmaita, 2018).

Students lacking scientific argumentation skills during the PBL process is a noteworthy challenge (Batdi, 2014). This arises because students are not explicitly guided in formulating accurate scientific arguments; instead, students are encouraged to solve problems without clear direction toward the criteria for developing proficient scientific argumentation skills (Akhdinirwanto *et al.*, 2020; Jumadi *et al.*, 2021). Another challenge is related to the existence of varying levels of problem understanding among students, accompanied by negative reflection on aspects such as problem formulation, data collection, group work, and all the possibilities that may arise throughout the learning process when implementing the PBL model (Palupi *et al.*, 2020).

4. Conclusions

This SLR examines prior research concerning the implementation of PBL models in science or chemistry education. The study focuses on 35 reputable articles, indexed by Scopus and Web of Science, and published between 2013–2023. The analysis reveals the following findings: **a)** The research trend in PBL implementation for science learning, particularly in chemistry, exhibits variations across different years. Predominantly, PBL research is conducted at the high school and university levels, with only a limited amount of research being done on PBL implementation at the elementary school level. The results of the study indicate that the majority of PBL research is concentrated in Asia (67.71%) and Europe (17.14%); **b)** the four dominant variables that emerged from previous research, namely thinking skills (20.48%), problem-solving skills (9.64%), conceptual understanding (8.43%), and argumentation skills (8.43%); **c)** Issues raised in PBL predominantly revolve around everyday problems faced by students, encompassing themes such as malnutrition and obesity, waste management, climate change, water, air, and soil pollution, green chemistry, and sustainability; **d)** common steps identified in PBL application by previous researchers encompass 6 stages: problem orientation, student organisation, independent study, group investigation and discussion, reporting and presenting the results, and evaluation and reflection; **e)** Several challenges encountered by previous researchers in the implementation of PBL in chemistry education. These challenges are related to time constraints, teacher proficiency, student characteristics, and the technical implementation of PBL.

This SLR contributes to providing insights into the application of the PBL model in chemistry education and clarifying the challenges encountered by researchers in earlier studies. In addition, we have identified common steps crucial to PBL through the investigation of the study's objects. These findings serve as valuable references for future researchers aiming to conduct studies on PBL in chemistry education and devise new strategies to address the shortcomings identified in prior studies.

Authors' contribution

Conceptualization: Fauzana Gazali; Sri Rahayu; **Data curation**: Munzil; Fauzana Gazali; **Formal Analysis**: Fauzana Gazali; **Funding acquisition**: Not Applicable; **Investigation**: Not Applicable; **Methodology**: Surdjani Wonorahardjo; **Project administration**: Fauzana Gazali; **Resources**: Munzil; **Software**: Fauzana Gazali; **Supervision**: Sri Rahayu; **Validation**: Sri Rahayu; Surdjani Wonorahardjo; **Visualization**: Fauzana Gazali; **Writing – original draft**: Fauzana Gazali; **Writing – review & editing**: Muhammad Dimar Alam; Sri Rahayu.

Data availability statement

All data sets were generated or analyzed in the current study.

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Conflict of interest

The authors declare that there is no conflict of interest.

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APPENDIX 1

Table A1. Step of Problem-based learning in previous research.

Step of Problem-based learning	Article Reviewed	Common Steps PBL
1. Identifying problem (problem orientation) 2. Analyzing and formulating problems (problem orientation) 3. Designing problem solution (problem orientation) 4. Implementing solution 5. Presenting (reporting), Evaluating, and reflecting (evaluating)	Kartamiharja *et al.* (2020) Laksmi *et al.* (2021) Pritasari *et al.* (2015)	1. Problem orientation c. Presenting ill structure problem d. Generating ideas for questions e. Develop a problem scenario f. Collect information needed for problem-solving. g. Consider potential solutions to solve the problem 2. Students organizing c. Forming heterogeneous small groups d. Determine the roles of group members 3. Independent study c. Out-of- class learning d. Assessing information from various learning source ex: mass media, social media, internet, articles, book, etc. 4. Group investigation and group discussion e. Sharing information with group member f. Critically evaluate the resources and knowledge they have collected g. Investigate to solve the problem h. Data analyzing 5. Reporting and presenting the results 6. Evaluation and reflection
1. Problem orientation (problem orientation) 2. Developing a problem scenario (problem orientation) 3. Out-of-class learning (independent study) 4. Expert group formation (students organizing) 5. Compile a problem-solving report and present it (reporting and presenting the result)	Tosun and Senocak (2013) Tosun and Taskesenligil (2013)	
1. group formation and problem presentation (problem orientation) 2. brainstorming (clarify the nature of the problem and identify their learning needs) 3. students delegate roles within the groups and share existing knowledge (students organizing) 4. independent study (independent study) 5. Students gather in groups to share and critically evaluate the resources and knowledge they have gathered (group investigation and group discussion) 6. Students work to solve a problem (group investigation and group discussion)	Overton and Randles (2015) Costa *et al.* (2023)	
1. Problem identification (problem orientation) 2. Students grouping (students organizing) 3. Developing the hypothesis 4. Finding the information (problem orientation) 5. Data analysis 6. Evaluate the solution (evaluation) 7. Presenting the results (reporting)	Günter *et al.* (2017) Batlolona and Souisa (2020)	
1. Orientation (problem orientation) 2. Discuss problem in the worksheet (group discussion) 3. help students by asking probing questions and fostering collaboration 4. design a study plan and use online and library resources outside of class (independent study) 5. Sharing their knowledge in group (group investigation and group discussion) 6. Lab work and subject presentations (reporting and presenting the results) 7. To introduce the next subject, the tutor offers the pupils another worksheet, briefly explains it, and presents the issue	Ayyildiz and Tarhan (2018)	
1. Minilecture 2. group formation (students organizing) 3. introduction of problem scenarios related to the topic studied 8. Group discussion (group investigation and group discussion) 4. Presenting group discussion results to another group (reporting and presenting the results) 5. Assessment according to the rubric (evaluation)	Valdez and Bungihan (2019) Baran and Sozbilir (2018)	
1.problem identification and motivation (problem orientation) 2.organization and investigation (students organizing) 3.argumentation building 4.argumentation session 5. Evaluation-reflection (evaluation)	Akhdinirwanto *et al.* (2020)	

Continue…

Step of Problem-based learning	Article Reviewed	Common Steps PBL
1. Problem orientation (problem orientation) 2. Group investigation (group investigation and group discussion) 3. Develop and present results (reporting and presenting the results) 4. Analyzing and reviewing each step that has been done in overcoming the problem (evaluation)	Cahyono *et al.* (2021)	
1. Illstructure problem identification (problem orientation) 2. Design a problem solution 3. Group structured inquiry (group investigation and group discussion) 4. Develop and present artifacts and exhibit (reporting and presenting the results) 5. Evaluation and reflection (evaluation)	Marthaliakirana *et al.* (2022)	
1. The teacher designs a problem scenario about amino acid and present it to the students in the form of case study (problem orientation) 2. Students were required to analyze the problem, identify the central issues, and propose solutions in groups (problem orientation) 3. Teachers guided, advised, and supported students to build core concepts and creative thinking skills 4. Students were encouraged to ask questions, clarify, and work together to solve the problem (group investigation and group discussion) 5. Teachers assess students' creative thinking using pre- and post-tests, interviews, and observations (evaluation)	Ernawati (2021) Ernawati *et al.* (2022)	
1. Understanding the problem 2. Explore the problem 3. Generate possible solution 4. Determine the best fit solution 5. Solve the problem by performing experiment 6. Evaluation	Yoon *et al.* (2014)	
1. Directing students to authentic problems 2. Facilitate student learning by forming collaborative groups that share ideas 3. Individual and group investigation 4. Presenting the results 5. evaluate the results of the problem-solving process	Simanjuntak *et al.* (2021)	
1. problem presentation (problem orientation) 2. problem identification (problem orientation) 3. self-investigation (independent study) 4. Data organization 5. Sharing finding	Rehmat and Hartley (2020)	
1. Defining Problem (problem orientation) 2. Determining information for addressing the problems (problem orientation) 3. Finding, evaluating, and utilizing information as evidence for their solutions 4. Generating an argument in support of the solution	Kim *et al.* (2019; 2022)	

Source: Elaborated by the authors.