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Enhancing problem-solving skills in chemistry through problem-based learning with SETS: a systematic review

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ABSTRACT

The development of 21st-century education in Indonesia necessitates equipping students with essential competencies such as problem-solving skills (PSS), particularly in chemistry learning, where real-world relevance is crucial. This study explores the integration of the Science, Environment, Technology, and Society (SETS) approach into Problem-Based Learning (PBL) as a strategy to enhance students' PSS in chemistry. Employing a Systematic Literature Review (SLR), this research analyzed 127 articles from five databases (SCOPUS, Google Scholar, Semantic Scholar, Taylor & Francis, and ERIC) published between 2020 and 2024. After applying inclusion and exclusion criteria based on relevance to PBL, SETS, PSS, and secondary chemistry education, 14 high-quality articles were selected for in-depth analysis. The review revealed that integrating SETS into PBL positively impacts students' ability to analyze, reason, and apply chemical concepts in solving contextual problems. However, challenges such as teacher readiness, curriculum constraints, and limited assessment tools were also identified. This study contributes to the literature by mapping trends and identifying best practices for implementing PBL-SETS in chemistry education. Despite its comprehensive scope, the review is limited by potential publication bias and the exclusion of non-English studies. These findings suggest the need for more empirical studies and professional development programs to support teachers in adopting PBL-SETS effectively.

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Introduction

In the era of 21st-century education, students are expected to master not only content knowledge but also essential competencies such as critical thinking, self-directed learning, and problem-solving skills (PSS) to engage with the complex and dynamic demands of modern society (Hughes, 2016). Among these skills, PSS stands out as a vital capability, enabling learners to analyze, evaluate, and respond effectively to real-world challenges. In the context of chemistry education—particularly at the secondary school level—this need is especially pressing. Chemistry plays a central role in understanding and addressing global issues such as environmental degradation, technological innovation, sustainable energy, and public health (Suseelan et al., 2022). However, despite the relevance of chemistry to everyday life, many students struggle to apply chemical knowledge to contextual problems, resulting in a persistent gap between theoretical understanding and practical application.

This gap has been observed in both developed and developing countries. A 2021 report by the National Science Teachers Association (NSTA) in the United States indicated that only 35% of high school students felt confident in using chemistry knowledge to solve real-world problems, such as water pollution or renewable energy evaluation (NSTA, 2021). Similarly, in Indonesia, student performance assessments have shown that learners often perform well on recall-based items but underperform in problem-based assessments requiring contextual reasoning (Zajuli et al., 2019). These findings suggest that traditional models of chemistry instruction—dominated by lectures, memorization, and procedural exercises—are insufficient in cultivating the higher-order skills necessary for solving interdisciplinary, real-life problems (Martaningsih et al., 2022).

Previous studies have highlighted the potential of student-centered pedagogies, such as Problem-Based Learning (PBL), to enhance PSS by engaging students in collaborative, inquiry-driven problem-solving tasks (Juandi & Tamur, 2021). PBL encourages learners to construct knowledge actively while developing skills in reasoning, critical thinking, and communication. However, most existing research tends to focus narrowly on cognitive outcomes, such as test scores or academic achievement, while giving limited attention to how PBL fosters real-world problem-solving or how it can be effectively implemented in school settings (Phungsuk et al., 2017). Furthermore, critical barriers to adoption—such as lack of teacher training, resistance to student-led learning, and contextual limitations—remain underexplored in the literature, resulting in an incomplete understanding of PBL's practical viability.

To address this limitation, researchers have proposed integrating PBL with the Science, Environment, Technology, and Society (SETS) framework, forming what is known as PBL-SETS. Theoretically, SETS offers a socio-scientific approach that contextualizes chemistry learning by connecting it with relevant real-world issues (Prahani et al., 2022). When combined with PBL, SETS enhances authenticity and relevance by encouraging students to apply chemical principles in contexts such as waste management, renewable energy, or environmental toxicity. For instance, students might investigate the chemical nature of plastic waste, evaluate its ecological impact, and develop feasible solutions for sustainable disposal (Akben, 2020). While PBL-SETS holds theoretical promise, empirical studies assessing its implementation in high school chemistry classrooms are still limited. Few investigations have evaluated how this integration influences PSS development, and even fewer have analyzed the structural and pedagogical challenges of its application in real educational environments (Warnock & Mohammadi-Aragh, 2016).

This research aims to address these gaps by conducting a Systematic Literature Review (SLR) that synthesizes current evidence on the use of PBL-SETS in secondary school chemistry education. The SLR method was selected for its ability to comprehensively and transparently collect, evaluate, and integrate findings across diverse studies (Xiao & Watson, 2019). Specifically, this review seeks to: (1) assess the effectiveness of PBL-SETS in enhancing students' problem-solving skills, and (2) identify key challenges and limitations in its classroom implementation.

By systematically analyzing literature from major databases—including Scopus, Google Scholar, Semantic Scholar, ERIC, and Taylor & Francis—this study contributes to the development of evidence-based insights for educators, curriculum developers, and policymakers. Beyond advancing the theoretical understanding of PBL-SETS, the findings aim to support practical improvements in classroom instruction, including the design of teacher training programs and curriculum frameworks that align with 21st-century learning goals. Ultimately, this study positions PBL-SETS as a transformative pedagogical model capable of bridging the gap between academic knowledge and societal relevance in chemistry education.

Method

This study employs a Systematic Literature Review (SLR) to evaluate the effectiveness of Problem-Based Learning integrated with Science, Environment, Technology, and Society (PBL-SETS) in enhancing problem-solving skills (PSS) in high school chemistry education and to identify associated implementation challenges. The SLR methodology was selected for its rigorous, transparent approach to synthesizing evidence, which is essential for addressing the fragmented literature on PBL-SETS and providing evidence-based insights for educators (Xiao & Watson, 2019). The SLR follows the structured framework proposed by Okoli (2015), comprising six key steps: identifying goals, developing protocols, applying inclusion/exclusion filtering, searching for literature, assessing article quality, and synthesizing studies. These steps ensure a systematic and replicable process to answer the research questions:

Identifying goals

The primary objective of this SLR is to assess the impact of PBL-SETS on PSS in high school chemistry education and to identify barriers to its implementation. This focus addresses the need to consolidate evidence on effective pedagogical strategies and practical challenges, as prior studies often lack comprehensive evaluations of PBL-SETS in this context (Prahani et al., 2022).

Developing Protocols

A detailed protocol was established to guide the literature search and ensure consistency. The search was conducted across five reputable databases: Scopus, Google Scholar, Semantic Scholar, ERIC, and Taylor & Francis. These databases were chosen for their extensive coverage of educational and scientific literature. The search used a combination of keywords: "Problem-Based Learning" AND "Science Environment Technology Society" AND "Problem Solving Skill" AND "High School" AND "Chemistry." Boolean operators were employed to refine the search, ensuring relevance to the research objectives. The protocol limited the search to peer-reviewed articles published between 2018 and 2023 to reflect recent developments in educational research, as recommended by Xiao and Watson (2019).

Applying practical screen/ inclusion filtering.

The third stage is inclusion filtering. At this stage, the reviewer performs filtering which aims to determine which articles will be used and which will not be used. In articles that are not used, the reviewer must write reasons related to the purpose or criteria of the article to be written. Inclusion filtering uses the SCOPUS, Google scholar, Semantic scholar, ERIC and Taylor and Francis databases. The keywords used are " Problem Based Learning" AND "Science Environment Technology Society" AND "Problem Solving skill" AND "High school" AND "Chemistry" .

Table 1 <Inclusion and Exclusion Criteria>

Criteria	Code	Inclusion	Code	Exclusion
Publication Time	IC1	2020-2024	EX1	Outside of that year
Language	IC2	English	EX2	English
Exposure of Interest	IC3	SETS integrated PBL strategy focus	EX3	Not related to SETS integrated PBL strategy
Participants	IC4	High school students	EX4	Not a high school student
Peer Review	IC5	Articles published in peer reviewed journals	EX5	Not through peer review
Reported Outcomes	IC6	Effectiveness of SETS integrated PBL	EX6	Not reporting the effectiveness of SETS integrated PBL strategies
Study Design	IC7	Empirical Research	EX7	Contains a literature review
Type of Publication	IC8	Journal Articles	EX8	Book chapter, proceedings, blog, news article, meta analysis

Searching for Literature

The literature search was conducted over a three-month period, from February to April 2025. Search terms were systematically applied in each database using the predefined Boolean logic, and the strategy was adapted as needed to accommodate different indexing systems. For instance, precise keyword variations and filters were applied in Google Scholar to ensure specificity, while advanced search filters were used in Scopus and ERIC. All retrieved articles were documented in Zotero and labeled based on initial relevance.

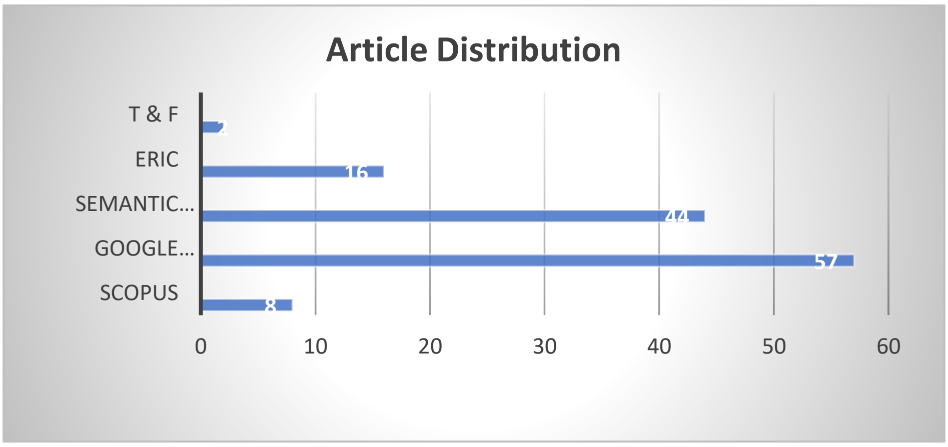

Figure 1 <Distribution of Articles>

This process enabled transparent screening and facilitated the traceability of articles throughout the review stages. The final selection of studies was guided by predefined inclusion and exclusion criteria, and the progression of article selection was illustrated using a PRISMA diagram, which includes detailed figures and justifications at each stage of inclusion or exclusion.

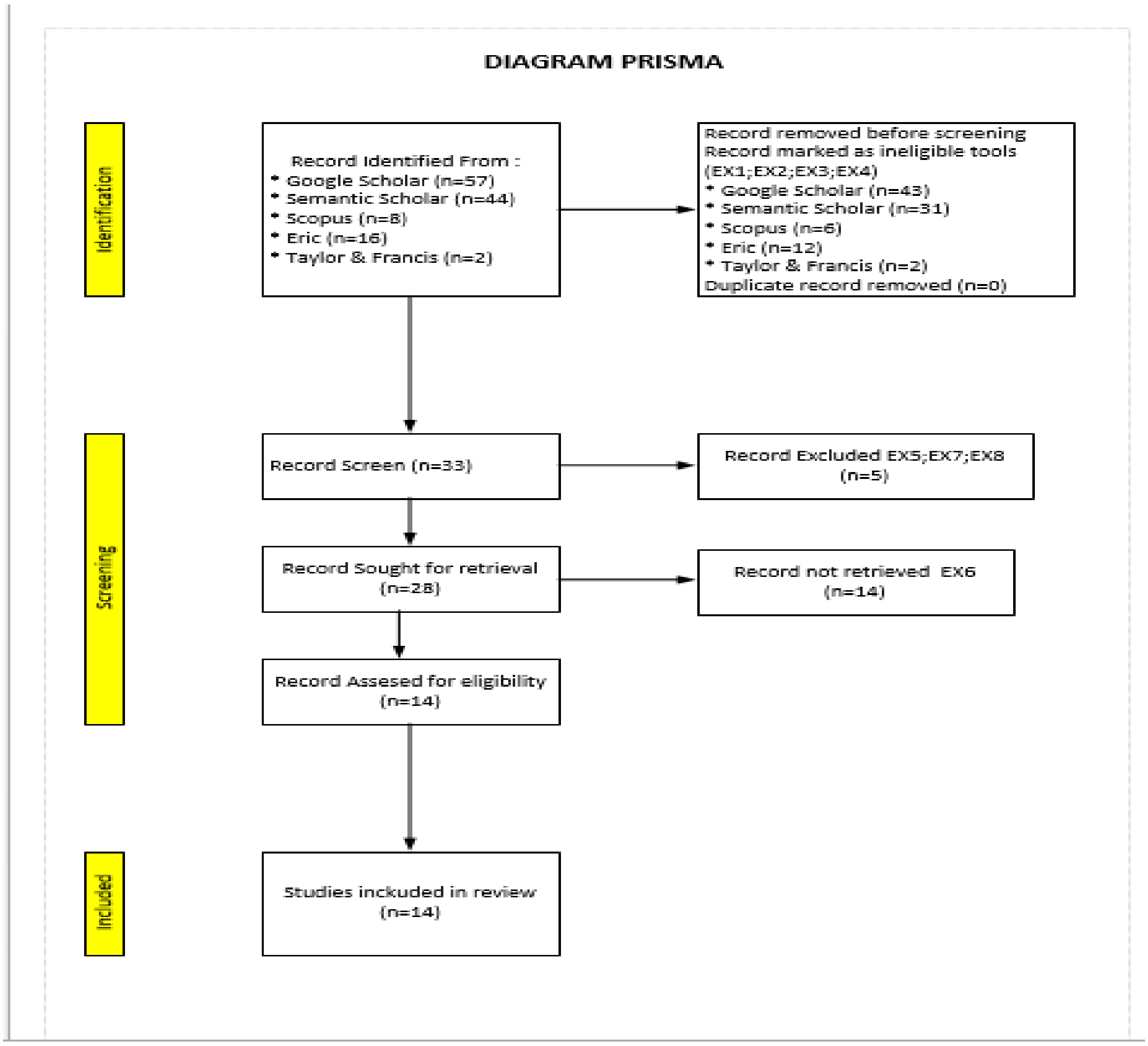

Figure 2 <PRISMA Diagram>

Synthesizing studies

The synthesis of data in this study was conducted using a thematic analysis approach, which allowed for the extraction of meaningful patterns and categories from the selected articles. The process began with an initial coding phase, in which key statements, findings, and relevant insights were identified from each article. These codes were then grouped into broader thematic categories that reflected the core focus areas of the research, particularly the effectiveness of the PBL-SETS approach and the implementation challenges faced in the classroom context. To ensure consistency and reduce the risk of bias, both reviewers independently conducted the coding and categorization processes, followed by a collaborative cross-review session to resolve any discrepancies and refine the themes.

Once the thematic framework was established, the reviewers engaged in a narrative synthesis of the findings. This involved integrating and interpreting the themes through descriptive summaries and illustrative evidence drawn directly from the studies. Themes such as the improvement of analytical reasoning, contextual application of chemical knowledge, increased student engagement, and teacher-related obstacles emerged consistently across the reviewed literature. The synthesized results were then validated through consultation with two subject-matter experts in chemistry education. Their feedback was instrumental in confirming the clarity, relevance, and educational implications of the identified themes. This triangulation process enhanced the validity and credibility of the study's conclusions, ensuring that the interpretations were grounded in both empirical evidence and expert judgment

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Extracting and assessing article quality

The 14 selected articles were evaluated using a qualitative rubric (Table 2) adapted from educational research evaluation frameworks. Assessment focused on the clarity of goals, theoretical grounding, research methodology, and significance of findings.

Table 2 <Qualitative Analysis Rubric>

Aspects/Criteria	**Assessment Score**			
	4 (Very good)	**3 (Good)**	**2 (Enough)**	**1 (Less)**
Goals and problems	Problems, objectives, reasons, research questions are formulated clearly	Problems, objectives, reasons, research questions are formulated adequately	Problems, objectives, reasons, research questions are formulated less clearly	Problems, objectives, reasons, research questions are formulated incompletely
Literature review	Critically examine field conditions. Places the topic clearly in a broader field. Makes convincing relationship to previous work. Discussing and resolving ambiguities in definitions. Synthesizing and evaluating ideas; offering new perspectives.	Discussing what has and hasn't been done done. Putting the topic in a broader field. Making relationship to previous work. Defining key vocabulary. Synthesizing and evaluating ideas	Discussing at least what has been and has not been done. Discussing vaguely a broader area. Making little relation to previous work. Lack of synthesis in the literature. Minimal evaluation of ideas. .	Failed to discuss what has and has not been done. The topic is not found in the wider literature. There isn't any relation to previous work.
Theoretical Framework	The theory is explained clearly, in detail, the framework is aligned with the study/	Theory aligned with objectives	Theories are only implied and explained vaguely, or are not aligned with the objectives.	There is no explanation of the theoretical basis
Participant	Participants were explained in detail and contextually about the population, sample and sampling procedures.	Participants are explained in detail and contextually about the population, sample	Participants are explained the basics	Participant not specified
Method	The research methodology is well designed, appropriate, and supports the research objectives effectively.	The methodology is quite good but there are aspects that do not provide maximum support.	The methodology has significant weaknesses but is still usable.	The methodology is inadequate or inappropriate for the research objectives.
Results and Conclusions	Data analysis is carried out in depth and detail with strong and relevant evidence.	The analysis is quite in-depth, but there are parts that are not supported by adequate evidence.	The analysis is shallow and lacks strength in supporting the main findings.	There is no clear analysis or supporting data.
Significance	The article provides new and significant insights into chemistry learning or education.	The article has novelty, but its impact is relatively small.	The article contribution is minimal and does not bring anything significant new.	There is no new contribution or just repeating previous research.

Results and Discussions

The systematic literature review analyzed 14 peer-reviewed articles to evaluate the effectiveness of Problem-Based Learning (PBL) integrated with the Science, Environment, Technology, and Society (SETS) framework (PBL-SETS) in enhancing problem-solving skills (PSS) in high school chemistry education, as well as to identify implementation challenges. The findings, summarized below, demonstrate the pedagogical value of PBL-SETS while highlighting key barriers that require strategic interventions. Based on the results of the analysis of 14 selected articles, the results are displayed as follows:

Effectiveness of PBL-SETS

The analysis revealed that PBL-SETS is consistently effective in enhancing students' PSS, as evidenced by six studies reporting significant improvements in analytical reasoning, contextual understanding, and application of chemical concepts (P1, P2, P4, P6, P8, P9) (Prahani et al., 2022; Zajuli et al., 2019). For instance, Prahani et al. (2022) found that PBL-SETS significantly improved students' ability to apply chemical principles to real-world problems, such as analyzing water pollution, with a reported effect size of 0.78. Similarly, Zajuli et al. (2019) observed enhanced collaboration and critical thinking in students tasked with solving interdisciplinary chemistry problems. In contrast, PBL alone was effective in three studies (P3, P5, P7), but its impact was less pronounced, with smaller effect sizes (e.g., 0.45 in P5) (Phungsuk et al., 2017). Other SETS-based methods, not integrated with PBL, showed weaker results in two studies (P10, P12), suggesting that the combination of PBL and SETS is uniquely effective in fostering PSS (Akben, 2020).

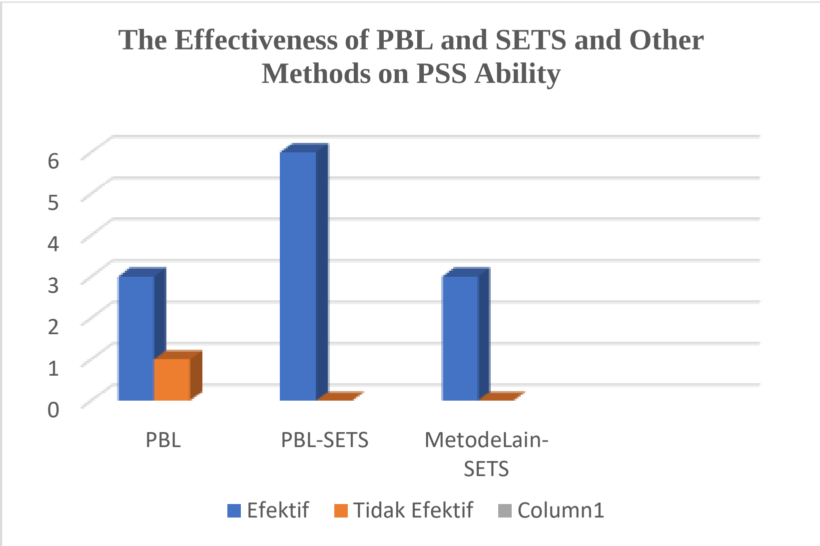

Figure 3 <PBL-SETS Effectiveness Graph>

Despite these promising results, the presentation of findings in Figure 3 lacks statistical rigor, such as effect size indicators or confidence intervals, which limits the ability to quantify the magnitude of PBL-SETS's impact (Novianti & Suryawati, 2021). To address this, future studies should report standardized metrics, such as Cohen's d, to enhance comparability (Xiao & Watson, 2019). Additionally, linking results to specific studies using codes (e.g., P1, P2) improves traceability, as recommended by systematic review guidelines (Rahman et al., 2022). Variations in effectiveness across studies suggest the influence of contextual factors, such as the chemistry subtopic or student demographics. For example, studies focusing on environmental chemistry (P4, P8) reported stronger outcomes, likely due to SETS's alignment with real-world relevance (Suseelan et al., 2022). This indicates that PBL-SETS may be particularly effective for socio-scientific topics, warranting further investigation into subject-specific applications (Wulandari & Sholihin, 2019).

The collaborative nature of PBL-SETS also fosters student engagement, as noted in studies emphasizing inquiry-driven tasks (Juandi & Tamur, 2021).The effectiveness of PBL-SETS aligns with constructivist learning theories, which emphasize active knowledge construction through meaningful, authentic experiences (Woolfolk, 2021). PBL-SETS engages students in real-world problem-solving, fostering deeper cognitive engagement and higher-order thinking skills, such as analysis and synthesis (Drigas & Papoutsi, 2018). By integrating SETS, the approach contextualizes chemistry within societal and environmental frameworks, enhancing students' motivation and understanding of chemistry's relevance (Araiza-Alba et al., 2021). This theoretical alignment underscores PBL-SETS's potential to bridge the gap between theoretical knowledge and practical application, a critical need in chemistry education (Saavedra & Opfer, 2012)

Implementation Challenges

Despite its effectiveness, PBL-SETS implementation faces significant challenges, categorized into four main areas, as shown in Table 3 and Figure 4. These barriers reflect both pedagogical and systemic issues that must be addressed to maximize the approach's impact.

Table 3 <Challenge Criteria>

Category	Coding	Article	Percentage (%)
Problem Solving Skills	Evaluation Ability	P8,P9,P14	18
	Difficulty in forming Hypothesis	P8,P9,P14	
	Limitations of Problem Solving	P1,P2,P8,P9,P14	
Student Adaptation Difficulties	Learning Independence	P1,P2,P4,P8,P9,P14	32
	Students' difficulties in adapting	P1,P2,P4,P6,P8,P9,P14	
	Dependence on teachers	P1,P2,P6,P8,P9,P14	
Teacher Challenge	Teacher facilitation	P1,P2,P4	13
	Designing Context Activities	PI,P2,P8,P9,P14	
Time and Resources	Time constraints	P1,P2,P4,P6,P8,P9,P14	20
	Complexity of Learning Media	P1.P2,P6,P8,P9	

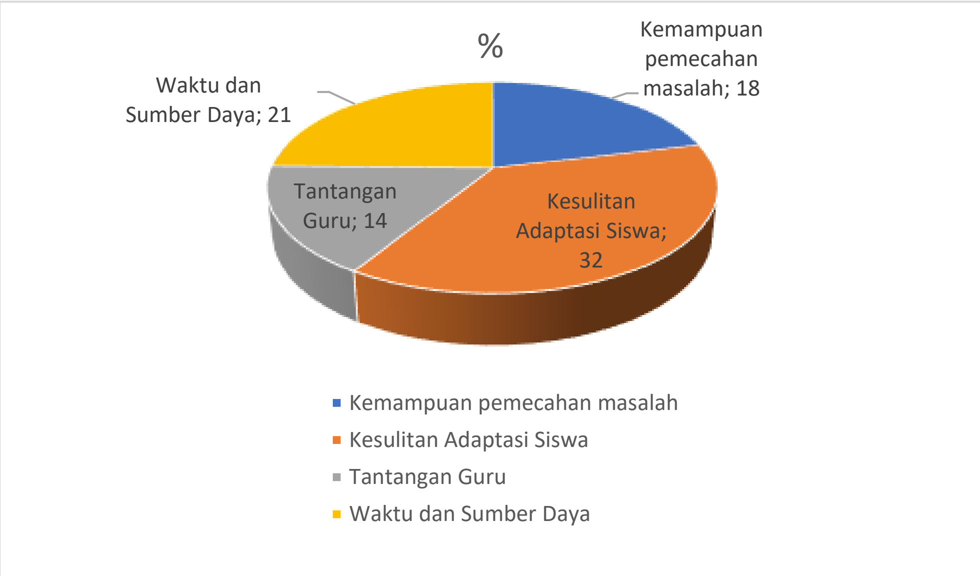

Figure 4 <PBL-SETS Challenges>

The most prominent challenge, cited in 32% of studies (P1, P2, P4, P6, P8, P9, P14), is students' difficulty adapting to the self-directed nature of PBL-SETS (Martaningsih et al., 2022). Students often struggle with open-ended problem scenarios, exhibiting low learning independence and limited experience in inquiry-based methods (Sari & Prasetyo, 2020). This aligns with findings that students require scaffolding to transition to student-centered approaches (Warnock & Mohammadi-Aragh, 2016). Implementing structured problem-solving templates or guided inquiry could mitigate this barrier (Kusuma & Widodo, 2021)

The second challenge, reported in 21% of studies (P1, P2, P4, P6, P8, P9), is time constraints and limited resources. PBL-SETS requires extended instructional time for contextualization, experimentation, and discussion, yet many schools lack adequate laboratory facilities or flexible schedules (Phungsuk et al., 2017). For example, P6 noted that limited lab equipment hindered hands-on experiments, reducing authenticity. Systemic interventions, such as low-cost teaching materials or curriculum redesign, are needed to address this (Hidayat & Susanti, 2022; Lestari & Santoso, 2022).

The third challenge, identified in 18% of studies (P1, P2, P8, P9, P14), is students' limited baseline problem-solving abilities. Despite PBL-SETS's design, some students struggle with critical evaluation and applying chemical principles to real-world scenarios (Zajuli et al., 2019). Explicit instruction in heuristic approaches could build cognitive readiness (Sinaga et al., 2023). Metacognitive strategies, such as reflective journaling, may further support skill development (Drigas & Papoutsi, 2018).

The fourth challenge, noted in 14% of studies (P1, P2, P4, P8, P9, P14), is teacher readiness. Educators often lack training in facilitating SETS-oriented activities, leading to reliance on traditional methods (Martaningsih et al., 2022). Professional development programs focusing on PBL-SETS pedagogy are essential (Okoli, 2015). Peer mentoring and collaborative lesson planning could also enhance teacher competence (Warnock & Mohammadi-Aragh, 2016)

In summary, while PBL-SETS significantly enhances PSS in high school chemistry education, its implementation is hindered by student adaptability, resource limitations, baseline skill gaps, and teacher readiness. Addressing these requires scaffolding, curriculum adjustments, explicit problem-solving instruction, and comprehensive teacher training, aligning with constructivist principles to foster 21st-century competencies (Amanda et al., 2022).

Conclusions

This systematic literature review synthesized findings from 14 high-quality studies to evaluate the effectiveness of integrating Problem-Based Learning (PBL) with the Science, Environment, Technology, and Society (SETS) framework in secondary school chemistry education. The results affirm that the PBL-SETS approach significantly enhances students' problem-solving skills (PSS), including critical thinking, analytical reasoning, and independent learning. By situating chemical concepts within authentic, real-world contexts, PBL-SETS fosters deeper conceptual understanding and increases student engagement in learning that reflects 21st-century challenges.

However, despite its promise, the implementation of PBL-SETS is not without challenges. The most notable obstacles include students' difficulty in adapting to self-directed learning environments, teachers' limited ability to design contextual learning experiences, and constraints related to time, instructional resources, and school infrastructure. These findings suggest that the successful application of PBL-SETS requires structural support, including comprehensive teacher professional development, curriculum alignment, and improved access to teaching materials and laboratory facilities.

It is important to acknowledge several limitations of this review. The analysis was restricted to articles published between 2020 and 2024 and predominantly written in English, which may have excluded relevant non-English or earlier foundational studies. Furthermore, the methodological diversity of the selected studies posed challenges in drawing generalized conclusions, as the research contexts, sample characteristics, and outcome measures varied significantly. The absence of meta-analytical techniques also limits the quantification of effect sizes. Potential publication bias must also be considered, as studies with positive results are more likely to be published and indexed in accessible databases.

Despite these limitations, this review offers meaningful contributions to the field of chemistry education by highlighting both the strengths and implementation barriers of PBL-SETS. Future research should explore longitudinal effects, develop standardized assessment tools for PSS, and investigate how PBL-SETS performs across different sociocultural and institutional settings. Practically, this study supports the strategic integration of PBL-SETS in curriculum development and provides evidence-based guidance for educators and policymakers seeking to advance science education through innovative, contextually grounded pedagogies.

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