



The Effects of Problem-Based Learning on Critical Thinking, Motivation, and Learning Outcomes in Indonesia: A Systematic Review

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Abstract: The Effects of Problem-Based Learning on Critical Thinking, Motivation, and Learning Outcomes in Indonesia: A Systematic Review. Objective: This study systematically examines the implementation of Problem-Based Learning (PBL) in teaching the reaction rate topic in Indonesia. It covers research methods, measured variables, implementation strategies, and media, as well as the effects of PBL on students' critical thinking, motivation, and learning outcomes. **Methods:** A systematic literature review was conducted following the PRISMA framework (identification, screening, eligibility, and inclusion) to ensure rigorous and transparent article selection. Articles published between 2015 to 2025 were retrieved using the Publish or Perish tool from Scopus and Google Scholar, resulting in 24 articles. Data were analyzed using Thematic synthesis based on Braun and Clarke's framework: (1) familiarization involved repeated reading of articles to understand content; (2) initial coding assigned meaningful labels to key data; (3) searching for themes grouped related codes; (4) reviewing themes refined coherence and relevance; (5) defining and naming themes clarified scope and meaning of each theme; (6) a coherent narrative synthesis integrated findings to highlight patterns and research gap. **Results:** The Use of PBL with students' worksheets (9 articles) proved to be the most effective in enhancing students' critical thinking, motivation, and learning outcomes in Indonesia. Research is dominantly quantitative (22 articles, 91.67%), with R&D limited (2 articles, 8.33%), indicating a need for more mixed-methods and qualitative research. A total of 12 articles (50%) investigated critical thinking, six articles (25%) focused on motivation, and 15 articles (63%) measured learning outcomes. No study simultaneously measured critical thinking and motivation, highlighting a research gap. Use of other media remains limited. **Conclusion:** Using PBL with students' worksheets and other instructional media effectively improves students' critical thinking, motivation, and learning outcomes on the reaction rate topic in Indonesia and guides the development of technology-integrated strategies, while encouraging future research on diverse methodologies and simultaneous measurement of cognitive and affective outcomes.

Keywords: critical thinking skills, learning motivation, learning outcomes, problem-based learning, reaction rate.

■ INTRODUCTION

The Problem-Based Learning (PBL) model has been widely recognized as an effective instructional approach to address the challenges of the 21st century by fostering critical thinking skills, enhancing learning motivation, and improving student learning outcomes, particularly at the secondary and vocational school levels (De Witte & Rogge, 2016; Nguyen, Ngo, Ngoc, & Hung, 2025; Hugerat, Kortam, Kassom, Algamil, & Asli, 2021; Suhirman & Prayogi, 2023; Ulucinar, 2023; Valdez & Bungihan, 2019; Wagino, Maksum, Purwanto, Simatupang, Lapisa, & Indrawan, 2024). Grounded in constructivist learning theory, PBL emphasizes that students actively construct knowledge through problem-solving and reflection (Chen, Kolmos, & Du, 2021; Hmelo-Silver, 2004; Matthews, 2002; Shimizu, Matsuyama, Duvivier, & Vleuten, 2021). In the context of

chemistry learning, which requires conceptual understanding as well as the ability to apply knowledge to real-world situations, PBL offers a meaningful learning experience that integrates both cognitive and motivational aspects (Aidoo, Boateng, Kissi, & Ofori, 2016; Dwikaryani, Rosbiono, & Sopandi, 2019; Nagarajan & Overton, 2019; Wellhofer & Luhken, 2022). Two competencies needed to handle these 21st-century challenges (critical thinking and motivation) have been shown to strongly influence students' academic success (Isa et al., 2023; Magwilang, 2022; Nsabayezu et al., 2022; Sa-ngiemjit, Alonso, & Mas, 2025). These competencies are closely interrelated with learning outcomes, where students must engage in higher-order thinking and problem-solving in chemistry learning (Nur'azizah, Utami, & Hastuti, 2021; Qi, Huang, & Zhang, 2024). Longitudinal studies have shown that critical thinking skills and academic achievement have a positive reciprocal relationship over time (Xiaojing, Jiabi, & Xuezhu, 2025). Therefore, the application of PBL in chemistry education is seen as a strategy to simultaneously develop critical thinking, increase student motivation, and enhance learning outcomes (Cahyani & Ahmad, 2024; Delgado, 2016; Lestari, Baiduri, & Ummah, 2024; Wellhofer & Luhken, 2022).

The application of chemistry learning, Students often have difficulty understanding scientific concepts related to contextual and open-ended problems, which hinders their ability to solve real-world problems (Kostikova et al., 2023). In addition, challenges in learning chemistry are caused by the abstract and complex nature of chemistry, which involves many theoretical concepts and calculations and requires critical thinking skills (Pratomo, Fitriyana, Wiyarsi, & Marfuaatum, 2025; Rodriguez, Harrison, & Becker, 2020; Salame, Ramirez, Nikolic, & Krauss, 2022; Williams et al., 2024). In addition to conceptual challenges, low active participation and low levels of interest among students have been identified as key factors that significantly impact academic motivation and critical thinking (Berestova, Kolosov, Tsvetkova, Grib, 2022; Fitri, Yuliani, & Laksono, 2023; Orakci, 2023; Rihmahwati, Harjono, Sumarti, & Prasetya, 2024; Sibomana, Karegeya, & Sentongo, 2021). Learning motivation is crucial because individuals without motivation will struggle to achieve learning objectives (Austin, Hammond, Barrows, Gould, & Gould, 2018; Emda, 2019). However, research indicates that students' learning motivation remains low, with some students lacking motivation altogether due to perceiving chemistry as difficult and confusing (Chairunnisa, Multihapasari, & Larasati, 2021; Liu, 2024). Conventional learning methods are still frequently applied, but they do not adequately address these needs (Putri & Mulyanti, 2024). Therefore, the application of PBL as a learner-centered model is a solution to make learning more active, foster curiosity, help students overcome the abstract and complex nature of chemistry, strengthen critical thinking skills, and student motivation to learn (Desi, Lesmini, & Hidayat, 2019; Purwanto, Rahmawati, Rahmayanti, Mardiah, & Amalia, 2022).

Chemistry education aims to train students in scientific thinking and problem-solving, rather than just memorizing formulas (Zhong, 2014). However, several challenges persist in the field, including learning difficulties and low learning outcomes among students, particularly in complex, abstract, and critical thinking-intensive topics (Gegios, Page, Escott, Silva, & Barding, 2018). In reaction rate material, it often faces challenges because it involves abstract concepts such as particle collisions, activation energy, and factors that affect reaction rates (Nangku & Rohaeti, 2019). Students often face difficulties in understanding reaction rates because they need to combine chemical

principles with mathematical reasoning, particularly when constructing graphical models of reaction rates (Rodriguez et al., 2020; Rushton et al., 2014). PBL helps to concretize concepts, train analysis, prediction, and data interpretation, while developing critical thinking skills (Arifin, 2020; Dakabesi & Luoise, 2019; Delgado, 2016; Thorndahl & Stentoft, 2020). Additionally, PBL enhances learning motivation, encourages independent information seeking, connects theory with practice, and facilitates deep understanding (Savery, 2006; Wellhofer & Luhken, 2022). In the context of teaching reaction rate material, PBL can provide a comprehensive framework while fostering 21st-century competencies, following the principles described by Hendarwati, Nurlaela, & Bachri (2021), Sebatana & Dudu (2022), and Klaharn, Rungrudee, Chaleoykitti, & Chakchaichonet (2025).

This challenge is crucial when studying abstract concepts, such as reaction rates, which form the basis for advanced topics like chemical equilibrium and enzyme kinetics. Reaction rate plays a crucial role in chemical equilibrium because it determines how quickly a system reaches a state of equilibrium (Jusniar, Effendy, Budiasih, & Sutrisno, 2020; Narayan, Valles, Venegas, Yi, & Narayan, 2021). Meanwhile, enzyme kinetics, which studies how enzymes catalyze reactions and influence the rate of substrate conversion, is directly dependent on the principles of reaction rate (Ault, 2011; Wong, Krycer, Burchfield, James, & Kuncic, 2015; Zielinski et al., 2024). Studies in Turkey show that there are fundamental misconceptions, ranging from understanding reaction rates, activation energy, rate constants, to graph interpretation (Cakmakci, Leach, & Donnelly, 2006; Cakmakci, 2010; Kirik & Boz, 2012). Similarly, students in Thailand have been found to struggle with reaction rate concepts due to mathematical complexity and multiple influencing factors, often demonstrating partial, incomplete, or incorrect understanding (Supasorn & Promarak, 2015). These findings are consistent with various international studies that also report similar difficulties due to abstract, complex material that requires critical thinking skills (Bain, Rodriguez, & Towns, 2018; Bain, Rodriguez, & Towns, 2019; Rodriguez, Bain, Towns, Elmgren, & Ho, 2019; Yan & Subramaniam, 2018).

Although many studies have demonstrated the effectiveness of PBL (Problem-Based Learning) in various subjects and levels of education, previous studies, such as Nggadung, Kuswandi, and Fadhli (2025) reviewing the effectiveness of PBL in general, Bagiani, Agustini, and Sudatha (2024) highlighting cross-disciplinary critical thinking development, Anggraeni, Prahani, Suprpto, Shofiyah, and Jatmiko (2023) focused on data related to problem-based learning models and critical thinking skills in the field of social science, and Nicholus, Muwonge, and Joseph (2023) examining PBL in physics learning, reported improvements in students conceptual understanding and problem solving skills. However, these studies remain at a general level to capture the unique challenges of learning reaction rates is not only complex but also requires students to integrate macroscopic, submicroscopic, symbolic, and contextual representations, as it is related to everyday phenomena and does not provide insights into how PBL addresses topic-specific difficulties in chemistry, particularly in reaction rates. Their contributions are valuable for establishing PBL's broad benefits, but they do not capture the nuanced pedagogical needs of teaching this complex domain. Therefore, a systematic review specifically examining the application of PBL in reaction rate is needed to provide a deeper and more relevant understanding. Therefore, this study aims to fill the research

gap by conducting a systematic review of the application of PBL specifically on the topic of reaction rates, which to date has been rarely studied despite its conceptual complexity and frequent difficulties for students. A general evaluation of PBL effectiveness cannot adequately inform teaching practices in topics like reaction rates, where misconceptions are deeply rooted and the need for contextualization is greater than in many other areas of science learning. So far, there has been no review summarizing the evidence of PBL application in reaction rate learning, so this review aims to fill that gap by presenting a synthesis of the role of PBL in supporting students' critical thinking skills, motivation, and learning outcomes.

SLR addressed this gap regarding the application of PBL on the topic of reaction rates in chemistry learning in senior high schools/vocational high schools. SLR is needed to systematically review relevant research based on specifically formulated research questions (Barricelli et al., 2019). The findings of this study are expected to serve as a basis for developing more innovative chemistry learning to improve critical thinking, learning motivation, and student learning outcomes. The research questions examined in this study are:

RQ1: How do the research methods used in studies related to PBL on chemistry reaction rate learning vary?

RQ2: What are the dominant dependent variables in PBL research on chemistry reaction rates?

RQ3: How effective are PBL strategies or media in improving critical thinking skills, motivation, and learning outcomes in reaction rates, as reported in the analyzed literature?

RQ4: What is the effect of PBL on critical thinking skills, learning motivation, and learning outcomes of students in the topic of reaction rate?

▪ METHOD

Research Design

This study used a Systematic Literature Review (SLR) design to critically analyze relevant research, following the PRISMA steps (identification, screening, eligibility determination, and inclusion) was conducted systematically and transparently so that it could provide evidence-based conclusions and map existing research trends and gaps (Moher, Liberati, Tetzlaff, & Altman, 2010; Page et al., 2021).

Search Strategy

Article searches were conducted on Google Scholar and Scopus over the past ten years (2015–2025). Articles were obtained using the keywords “critical thinking skill AND reaction rate,” “motivation learning AND reaction rate,” and “problem-based learning OR PBL AND critical thinking OR motivation OR learning outcomes AND reaction rate.” In the initial stage, 884 relevant articles were identified, with 28 duplicates removed. Next, the remaining 856 articles were selected based on their titles and abstracts, resulting in 59 articles chosen for thorough reading. The article selection or screening process is shown in Figure 1. The first author screened the titles and abstracts, while the second and third authors only provided input during the discussion and writing stages. In cases where there were differences in screening decisions, the final decision

was made through discussion and consensus among all authors. This limitation was acknowledged, as it had the potential to cause bias; therefore, strict inclusion and exclusion criteria were used to minimize it.

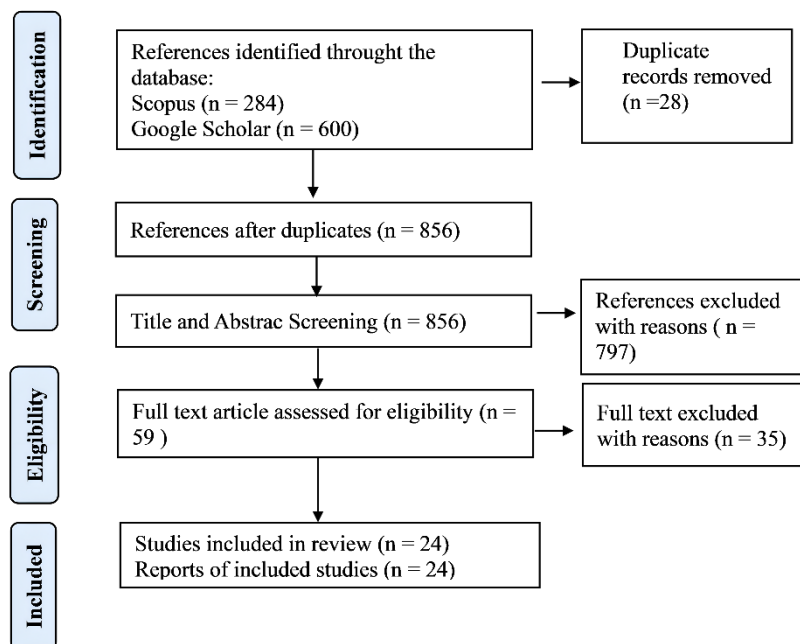


Figure 1. PRISMA flow diagram

Inclusion and Exclusion Criteria

The quality of SLR studies needs to be maintained through the use of a quality assessment protocol. These criteria are used to assess the quality of selected studies, as they help researchers determine the strength of the conclusions drawn and facilitate the selection of the most relevant studies (Memon, Sami, Khan, & Uddin, 2020). In this study, the protocol applied included inclusion and exclusion criteria.

These articles were then selected based on predefined inclusion and exclusion criteria (see Table 1). They met the criteria for further analysis, focusing on the implications of the problem-based learning model on students' critical thinking skills, motivation, and learning outcomes in studying reaction rate material. Data extraction was carried out after the articles were selected. At this stage, the relevant data from each study were extracted. Each article details such as title, author, year, objective, method, PBL strategies/media, impact on students, evaluation methods, and main findings. Data extraction was performed by the first author. Each step was performed systematically to ensure consistency and minimize bias. The complete data extraction table for all 24 articles is provided in Appendix E for further analysis. The quality of the included articles was assessed using the Mixed Methods Appraisal Tool (MMAT), which allows for evaluation of methodological rigor. Of the 24 articles, 13 were rated as high quality and 11 as medium quality, and the results (presented in Appendix F) were used to consider the strength of evidence in the discussion.

Table 1. Inclusion and exclusion criteria

No.	Category	Inclusion Criteria	Exclusion Criteria
1.	Publication type	Articles published in journals and proceedings.	Books, magazines, newspapers, book chapters, theses, dissertations, conference abstracts only, reports.
2.	Journal specification	International journals indexed by Scopus and national journals (The articles were obtained through the Scopus and Google Scholar databases because both offer broad coverage, ease of access, and high relevance to international and national literature. Meanwhile, other databases, such as Web of Science and ERIC, were not used due to limited access and overlapping coverage with the two databases.	Articles not published in international journals indexed by Scopus or national journals
3.	Research Methods	Quantitative, R&D, Qualitative, and mixed methods. Although the inclusion criteria included qualitative research or mixed-methods studies, no relevant qualitative or mixed-methods articles were found during the screening process. This absence may limit perspectives and is considered a significant limitation, potentially affecting the completeness and diversity of evidence.	Other articles that do not employ quantitative, R&D, qualitative, or mixed methods.
4.	Year publication	A ten-year time frame, 2015 to 2025, was chosen to ensure that the studies analyzed were recent and relevant, while also covering a sufficient amount of literature to identify trends and developments in the field.	Articles published before 2015 or after 2025
5.	Research theme	Improving critical thinking skills, learning motivation, and learning outcomes of students through the Problem-Based Learning (PBL) model in chemistry learning, especially in reaction rate material.	Articles unrelated to PBL improving critical thinking, learning motivation, and learning outcomes, chemistry education, or reaction rate material.
6.	Areas of application	Chemistry Education	Articles outside chemistry education (e.g., biology, physics, mathematics, engineering, medicine).
7.	Language	Articles in English and Indonesian.	Articles in other languages.
8.	Acces	Full-text available (open access)	Abstract - only articles or not open access

Data Analysis

Data analysis of the 24 selected articles used a thematic synthesis approach to answer the four research questions (RQ1–RQ4). This approach follows Braun and Clarke's six-step thematic analysis framework: (1) familiarization involved repeated reading of articles to understand content; (2) initial coding assigned meaningful labels to key data; (3) searching for themes grouped related codes; (4) reviewing themes refined coherence and relevance; (5) defining and naming themes clarified scope and meaning of each theme; (6) a coherent narrative synthesis integrated findings to highlight patterns and research gap (Braun & Clarke, 2006).

▪ RESULT AND DISSCUSSION

To facilitate data analysis and presentation, the articles analyzed in this study were coded A1 to A24. Full details of the articles can be found in Appendix B. Based on the results of the selection process, this study utilized 24 articles for further analysis. The research method in the PBL reaction rate study is presented in Figure 2, while the research design is detailed in Table 2 below. This thematic synthesis highlights the variation of research methods (RQ1), which is discussed in section 4.1.

Table 2. Details of the method used

Design	Frequency	Method	Percentage
Quasi-experiment	16	Quantitative	91.67%
Pre-experiment	3		
True- experiment	2		
Quantitative descriptive	1		
ADDIE	2	R&D	8.33%

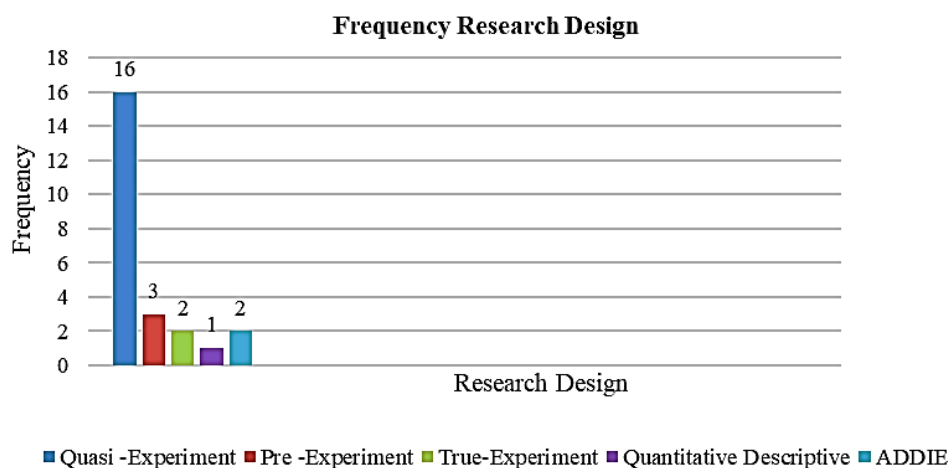


Figure 2. Distribution of PBL research methods in reaction rate material.

Variation of Research Methods (RQ1)

Thema 1: Methods

Most of the articles in this study were sourced from SINTA 2-4 accredited journals, reflecting the quality and validity of the data sources (see Appendix A). An analysis of

24 articles, according to the inclusion criteria, reveals that quantitative approaches dominate studies related to the application of Problem-Based Learning (PBL) in reaction rate learning, with 22 articles employing quantitative methods (91.67%) and only two articles utilizing Research and Development (R&D) (8.33%).

This is reflected in a content study conducted on articles in the field of Physical Education during 2006–2023, which shows that quantitative approaches such as questionnaires, tests, and quasi-experimental designs dominate, while qualitative research is still very limited (Rozi et al., 2025). Research by Susetyarini & Fauzi (2020) shows that quantitative approaches are most commonly used in critical thinking studies in Indonesia, with quasi-experimental designs accounting for approximately 52.6%. This method is more practical to apply in the classroom, and the results are easier to compare statistically. Quantitative methods are primarily chosen because they are considered objective and efficient, facilitating evaluation through indicators such as pre-tests and post-tests (Lim, 2024; Smith & Hasan, 2020). Additionally, accreditation requirements, lecturer performance evaluations, and scientific publication requirements also encourage the use of this method because it is more readily accepted by various academic journals and assessment institutions (Havey & Chang, 2022; Kaur, Ferrara, Menczer, Flammini, & Radicchi, 2015; Nguyen, Pham, Cox, & Bui, 2021; Polnaya, Nirwanto, & Triatmanto, 2018). The dominance of quantitative-experimental research in Indonesia is influenced by research culture, accreditation requirements, and faculty performance evaluations. One structural factor is the higher education accreditation system in Indonesia, managed by BAN-PT, which places greater emphasis on quantitative evidence in assessing institutional quality (Pratiwi & Kusumah, 2024). This encourages lecturers and researchers to choose research methods that produce numerical data that is easy to measure and compare. For example, a study by Hartono, Roostika, and Muslichah (2025) shows that the adoption of an accreditation information system is influenced by perceptions of usefulness and alignment with existing processes, which are often measured quantitatively.

However, the dominance of quantitative-experimental methods makes the understanding of PBL focused on measurable results, such as test scores and learning outcomes, so that complex and contextual learning processes are less explored. For example, research by Haryati (2014) shows that the implementation of school accreditation programs in Indonesia faces technical and procedural challenges, which are often not reflected in quantitative data. In fact, qualitative approaches such as case studies, observations, and interviews are better equipped to capture important dynamics, including group interactions, the development of students' intrinsic motivation, and how students formulate solutions in the learning process. An example can be found in qualitative research on the implementation of PBL in Indonesian language lessons in elementary schools, which used observation and interviews to explore students' critical thinking and creativity (Mardiyanto, Wulandari, Pratiwi, & Nugrahaini, 2024).

Meanwhile, two articles related to R&D research (A4 & A20) used the ADDIE model, which focuses on developing PBL-based teaching materials and e-modules to improve student learning outcomes and critical thinking skills. In addition, Research and Development (R&D) is also rarely used, and mixed methods are not found, even though both have great potential. The R&D research can produce PBL learning models or products that are applicable, contextual, and enrich contributions in the form of learning

innovations, rather than merely measuring effectiveness (Klaharn et al., 2025; Munawarah, Haji, & Maulana, 2020).

The dominance of quantitative methods is consistent with the research focus on student learning outcomes, which is the most frequently measured variable (16 articles, 66.7%), compared to critical thinking skills (12 articles, 50%) and motivation/interest in learning (6 articles, 25%), as presented in Figure 3. This shows that cognitive aspects, including learning outcomes and critical thinking, are easier to measure through tests, while affective aspects, such as learning motivation, require more flexible and in-depth assessment methods. According to research by Potgieter, Filmlalter, and Maree (2025), measuring affective outcomes objectively has proven to be difficult, so educational research often prefers cognitive assessment.

Methodological quality assessment using MMAT (Appendix F) showed that 13 articles were of high quality and 11 articles were of moderate quality. Therefore, findings related to learning outcomes and critical thinking skills can generally be considered reliable, with greater confidence placed in the results of high-quality studies. These findings reflect the dominant trend in educational research in Indonesia, particularly in PBL, which tends to use experimental approaches to measure the effectiveness of learning interventions (Palupi, Subiyantoro, Rukayah, & Triyanto, 2020; Shiddiqi, Purwaningsih, & Pujiana, 2025; Susanti, Suyanto, Jailani, & Retnawati, 2023). The limited use of qualitative methods, mixed methods, and R&D indicates opportunities to expand approaches in exploring the PBL model for reaction rate material.

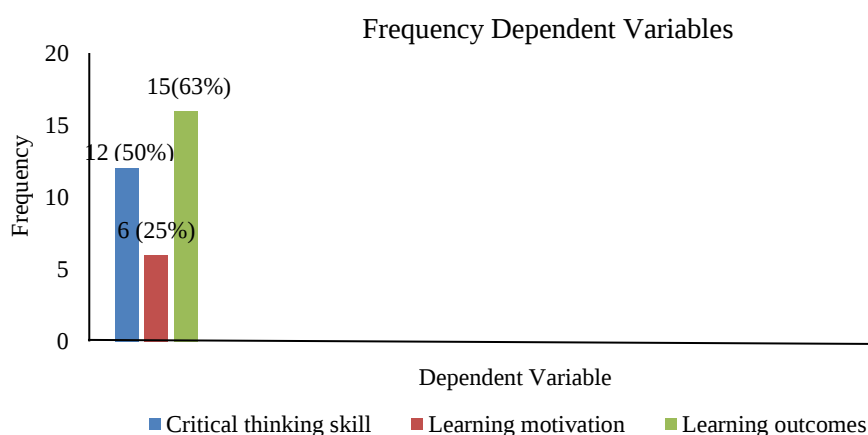


Figure 3. Distribution of dependent variables about PBL research on reaction rate material

Thema 2: Design

The research design in the quantitative approach consisted of quasi-experimental studies (16 articles), pre-experimental studies (3 articles), actual experimental studies (2 articles), and quantitative descriptive studies (1 article). The dominance of quasi-experimental designs suggests a tendency to measure the effectiveness of PBL implementation in terms of educational variables. However, it does not allow for strict randomization and remains empirically controlled (Gopalan, Rosinger, & Ahn, 2020). Article A1 presents a typical quasi-experimental study, in which treatment is applied to an experimental class and a control class, using pre-selected subjects from the school

without randomization. Although its internal validity is lower than that of a pure experiment, quasi-experiments are considered more practical for field applications (Maciejewski, Curtis, & Dowd, 2013; Maciejewski, 2020).

Dominant Dependent Variables (RQ2)

Beyond research methods, this study also examined the dominant dependent variables investigated in PBL research on reaction rate materials (RQ2), as detailed in the following section.

Thema 1: Critical Thinking Skill

The results of the review of 24 articles are presented in Figure 3, which shows that critical thinking skills appeared in 12 articles (50%). The terms “learning interest” and “learning motivation” are used interchangeably in some articles, so both are grouped into one category in the analysis. Critical thinking skills and learning motivation are key components in problem-based learning that determine the success of the learning process. PBL is explicitly designed to encourage active student engagement in developing higher-order thinking skills such as critical thinking and problem-solving (Hmelo-Silver, 2004). Additional evidence suggests that a specifically adapted PBL model can significantly enhance students' critical thinking skills (Garil, 2024; Yu & Zin, 2023). Another study by Francisco, Garzón, Grace, Manrique, and Mtr (2025) in the context of elementary education also showed a significant increase in critical thinking skills (score 4.2/5) through the implementation of PBL.

Thema 2: Motivation Learning

The results of the review of 24 articles are presented in Figure 3, which shows that learning motivation/interest was studied in 6 articles (25%). The terms “learning interest” and “learning motivation” are used interchangeably in some articles, so both are grouped into one category in the analysis. On the other hand, students' intrinsic motivation is one of the key factors stimulated by problem-based learning. This aligns with a meta-analysis by Wijnia, Noordzij, Arends, Rikers, and Loyens (2024), which concluded that PBL has a positive impact on learning motivation, including intrinsic motivation and perceptions of task value. Another study by Francisco, Garzón, Grace, Manrique, and Mtr (2025) in the context of elementary education also showed a significant increase in learning motivation (score 4.0/5) through the implementation of PBL.

Thema 3: Learning Outcomes

The results of the review of 24 articles are presented in Figure 3, which shows that learning outcomes are the most frequently measured dominant variable in the application of PBL for reaction rate material, with 15 articles (63%). This finding suggests that most PBL research on reaction rate materials continues to focus on cognitive aspects, particularly student learning outcomes. This aligns with a trend analysis in Indonesia, which shows that student competencies can be achieved through PBL research in chemistry education, including learning outcomes, critical thinking skills, motivation, and creativity (Suryanti & Nurhuda, 2021; Shiddiqi & Setiyawan, 2024; Shiddiqi et al., 2025). Meanwhile, affective aspects such as learning motivation are still relatively rarely studied in depth.

Interestingly, this review has not yet found any articles that examine critical thinking and learning motivation simultaneously in the context of PBL on the topic of reaction rates. This gap presents opportunities to explore the interaction between cognitive and affective aspects in conceptual and applied chemistry materials.

Effectiveness of PBL Strategies or Media (RQ3)

Beyond research methods, dominant dependent variables, this study also examined the effectiveness of PBL strategies or media investigated in PBL research on reaction rate materials (RQ3), as detailed in the following section.

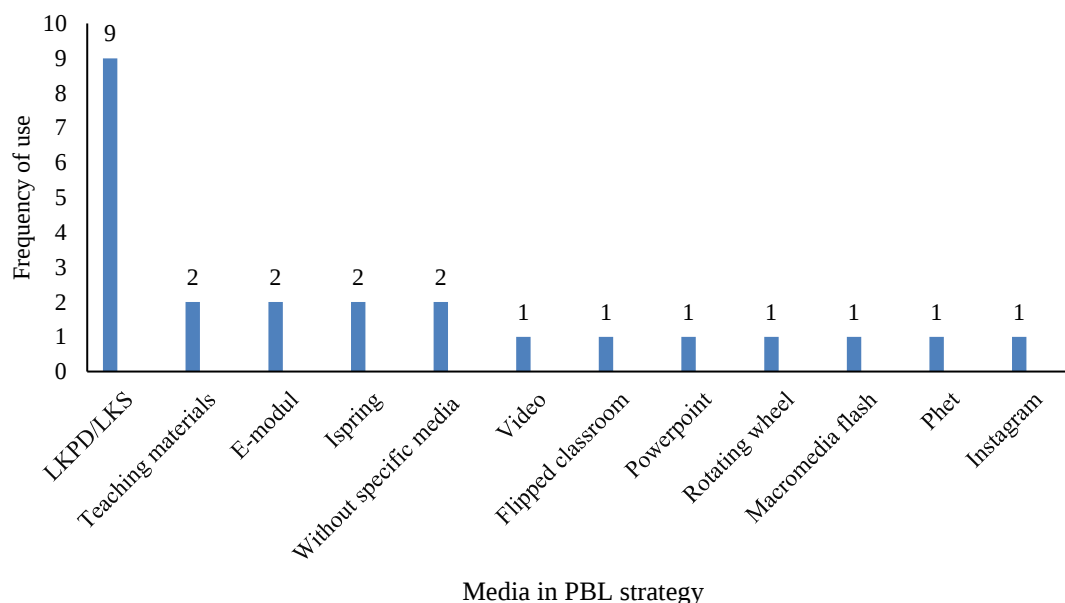


Figure 4. Distribution of Media in the Implementation of PBL on Reaction Rate Material

Thema 1: Strategies/Media

One of the 24 articles analyzed reported that although the implementation of PBL improved students' critical thinking skills, the improvement was still in the “moderately critical” category (Kasmianti, Tahril, & Tiwow, 2020). This is due to obstacles during the learning process, such as students' unpreparedness to adapt to a learning model that requires active involvement in problem-solving. The study also noted that some students had difficulty adjusting because they were not accustomed to problem-based learning. In addition, Abdullah, Syaharuddin, Husain, Yasriuddin, & Mendrofa's (2025) research highlights the limitations of PBL, such as its ineffectiveness for less active students, as well as the need for more time and resources. Another study by Basit, Muslim, and Saridewi (2023) also shows that time constraints are an obstacle to the optimal implementation of this model.

Although media frequency is lower, such as e-modules, instructional materials, videos, Macromedia Flash, iSpring, PhET Virtual, Instagram, and PowerPoint are increasingly being used in PBL implementation because they have been proven to enhance motivation and learning outcomes through interactive and contextual approaches

(see articles high quality A11, A24) and (see articles moderate quality A18, A10). As educational technology advances, interactive simulations have proven to enrich chemistry learning, particularly in visualizing abstract concepts (Jere & Mpeti, 2024; Rahmawati, Hartanto, Falani, & Iriyadi, 2022). Digital innovations, such as virtual PBL, can also strengthen experimental and problem-solving skills in the context of remote chemistry education (Williams, 2022). More broadly, the integration of digital technology is essential for addressing the challenges of 21st-century education, particularly in developing competencies such as critical thinking, creativity, and collaboration (Ramaila & Molwele, 2022; Voogt, Erstad, Dede, & Mishra, 2013).

Table 3. PBL strategies/media

No.	PBL Strategies/Media	Impact on Students	Evaluation Methods
1.	Problem-based STUDENTS' WORKSHEETS	Improved Critical Thinking skills	Essay test and questionnaires
2.	Video-assisted PBL model	Improved Critical Thinking Skills and Outcomes Learning	Essay test (critical) and multiple choice questions (learning outcomes)
3.	Flipped classroom-assisted PBL model	Improved Critical Thinking Skills	Test
4.	Virtual PhET-assisted PBL model	Improved Critical Thinking Skills	Essay test
5.	Instagram-assisted PBL model	Improved Motivation and Outcomes Learning	Multiple choice tests (learning outcomes) and questionnaires (motivation)

Table 3 summarizes the five main strategies used in the implementation of PBL. Media such as PhET virtual simulations are often used to enhance critical thinking, while Instagram supports improved learning motivation, and a flipped classroom facilitates improved critical thinking. The study employed Instagram as a learning medium to present the topic of reaction rates using visual and interactive content (such as images, short videos, and captions). This approach was found to increase students' motivation and facilitate a deeper understanding of chemical concepts (Widarti, Rokhmin, Yamtinah, Shidiq, & Baharsyah, 2024). Meanwhile, in the context of reaction rate learning, the flipped classroom within PBL fosters more active classroom engagement, provides opportunities for deeper problem-solving, and enhances critical thinking, particularly among students with higher critical thinking skills (Paristiowati, Cahyana, & Bulan, 2019).

The subject of reaction rates in chemistry covers abstract concepts such as particle collisions and activation energy, which are microscopic in nature and difficult to visualize through text or verbal explanations alone. Visual media such as animated videos and PhET simulations are important tools for bridging these concepts into more concrete representations that are easier for students to understand. The effectiveness of this medium can be explained through Cognitive Load Theory, which divides mental load into three types: intrinsic, extraneous, and germane load (Sweller, 1988). Videos and simulations help reduce extraneous load by presenting information in a focused, visual, and interactive manner, so that students do not need to imagine abstract processes on their

own (Liao, Chen, & Shih, 2019; Wieman et al., 2008). For example, PhET simulations allow students to directly observe the dynamics of collisions and the effects of temperature or catalysts on reaction rates to improve students' conceptual understanding in chemistry learning (Rahmawati et al., 2022). Similarly, educational videos designed according to multimedia learning principles have been proven to make learning more effective (Fan, Bower, & Siemon, 2024). In addition, this medium also increases germane load because it supports active cognitive engagement through simultaneous processing of visual and auditory information (Costley & Lange, 2017). Thus, visual media not only facilitate the understanding of abstract reaction rate concepts but also support more efficient and meaningful information processing in accordance with the principles of Cognitive Load Theory.

Thema 2: Impact on Students

These findings confirm that not all PBL implementations produce significant positive impacts, and that there are practical challenges that must be considered in its application in the classroom. On the other hand, research by Nur Hidayah, Azizah, and Nasrudin (2024) yields more positive results, showing a significant increase in critical thinking skills through the application of students' worksheets-based PBL. This shows that the effectiveness of PBL is highly dependent on the context of its implementation and design, including student readiness, facility support, and the learning strategies used.

The application of PBL in chemistry learning, particularly in reaction rate material, has shown positive effects on various aspects of student learning. It significantly improves critical thinking skills, as supported by 12 out of 24 studies (e.g., A1, A2, A3, A5, A7, A8, A9, A16, A20, A21, A22, A23). It also enhances student motivation, as found in 6 studies (e.g., A6, A10, A18, A24), and increases learning outcomes, with 15 studies reporting improvement (e.g., A2, A4, A8, A9, A11). These findings confirm that PBL is a promising approach for strengthening both cognitive and affective domains in chemistry education.

Thema 3: Evaluation Methods

The results of the analysis of 24 articles show that the evaluation methods (see Appendix C) used in the implementation of Problem-Based Learning (PBL) implementation is still dominated by essay tests and questionnaires, indicating a need for the development of more contextual and authentic assessments. The limitations of traditional assessment methods (essays and questionnaires), which only measure outcomes, make authentic assessment important because it evaluates the process, products, and performance of students comprehensively. Authentic assessment has been proven to enhance learning motivation, perseverance, learning outcomes, and student engagement in learning, while also developing 21st-century competencies such as critical thinking, problem-solving, creativity, and collaboration (Koh et al., 2019). The implementation of authentic assessment in PBL can facilitate deeper reflection and stronger conceptual understanding, especially when co-constructed with students in a supportive learning community (Barber, King, & Buchanan, 2015). Thus, the effectiveness of PBL can be enhanced by shifting from traditional tests to authentic assessments, such as project rubrics, performative assessments, portfolios, and product-

based assessments, to comprehensively capture the learning process while reflecting students' actual abilities.

Effect of PBL on Critical Thinking, Motivation, and Learning Outcomes (RQ4)

Beyond research methods, dominant dependent variables, the effectiveness of PBL strategies, or media, this study also examined the effect of PBL on critical thinking, motivation, and learning outcomes as investigated in PBL research on reaction rate materials (RQ4), as detailed in the following section.

Table 4. The effect of PBL on critical thinking skills, motivation, and learning outcomes

Author code	Main findings	Evidence of influence	Implementation Context
A1	PBL with students' worksheets improves critical thinking skills	The experimental group scored 79.42% compared to 58.02% (control), and the calculated t-value (6.83) was greater than the t-table value (2.04), indicating significance.	PBL with students' worksheets vs Teacher-centered learning
A11	PowerPoint-assisted PBL is superior to conventional learning in terms of learning outcomes and interest.	The experimental class showed higher improvement in learning outcomes (pretest 25.29, posttest 80.88; N-gain 0.6842) compared to the control class (pretest 24.41, posttest 74.12; N-gain 0.6315), Learning interest also increased in the experimental class (pretest 69.59, posttest 80.00; N-gain 0.1111) more than in the control class (pretest 65.00, posttest 70.76; N-gain 0.0625).	PBL assisted by a PowerPoint presentation in the experimental class vs. conventional teaching in the control class.
A16	PBL assisted by PhET significantly improves critical thinking	The Kruskal–Wallis test showed a significant difference (sig = 0.000) between classes, with the experimental class achieving higher critical thinking scores (81.47% vs. 74.26%) and overall performance (80.67% vs. 73.21%) than the control class.	PBL with PhET simulations vs. Discovery Learning.
A13	PBL assisted by Macromedia Flash improves student learning outcomes.	Higher student activity (t = 2.36) and learning outcomes (t = 4.43); activity contributed 64% to outcomes, showing a strong link.	PBL using Macromedia Flash in the experimental class vs. PBL using PowerPoint in the control class.
A15	PBL assisted by e-modules improves learning outcomes.	The experimental class achieved higher learning outcomes (N-gain 0.71) and interest (N-gain 0.54) compared to the control, with a strong correlation (r =	PBL-based electronic module vs. textbook-based learning.

		0.764) between interest (motivation) and achievement.	
A6	Improved learning outcomes and motivation to learn.	(t calculated = 3.2669 $\geq$ t table = 1.671; N-gain = 0.57, high) for students' learning outcomes and learning motivation (t calculated = 17.452 $\geq$ t table = 1.671).	PBL using problem-based teaching materials vs. conventional student handbooks.

Thema 1: Main findings

The analysis results present six main articles, as shown in Table 4. PBL has been proven to have significantly improved. For example, Article A1 shows that students who learn using PBL have higher critical thinking scores and essay test scores compared to the control group, with a calculated t-value (6.83) far exceeding the table t-value (2.04), indicating statistical significance. This finding reinforces the argument that PBL encourages active student engagement in problem-solving, thereby enhancing higher-order thinking skills. The following article, A8, demonstrates that integrating video media into the PBL model can simultaneously improve learning outcomes and critical thinking, with a strong correlation between the two ($r = 0.837$). The use of interactive media in the PBL context can optimize student engagement and understanding.

In addition, learning outcomes and interest also increased significantly when the PBL model was combined with media PowerPoint, as reported in article A11. The average learning outcomes and learning interest scores increased in both classes, but the increase in the experimental class was higher than in the control class. This is evident from the higher N-Gain scores for learning outcomes (68% vs. 63%) and learning interest (11% vs. 6.25%) in the experimental class.

Article A16 demonstrates that the implementation of PBL assisted by PhET significantly improves critical thinking. The implementation of PBL can significantly enhance students' chemical literacy and critical thinking skills compared to non-PBL methods. Furthermore, article A13 shows implementation of PBL assisted by Macromedia Flash improves student learning outcomes in reaction rate material, as evidenced by a Mann-Whitney test showing Asymp. Sig. (2-tailed) = 0.002 < 0.05. Article A15 about the implementation of PBL assisted by e-modules showed higher gains in learning outcomes (N-gain: 0.71) and interest (N-gain: 0.54) than the control class, with a strong positive correlation ($r = 0.764$) between interest and learning outcomes. Meanwhile, article A6 showed that students taught with problem-based materials demonstrated greater improvement in learning outcomes and motivation, as indicated by regular handbooks; student response to the materials was 76.04% (in the good category).

Thema 2: Evidence of Influence

The analysis of 24 studies indicates that Problem-Based Learning (PBL) is effective in enhancing students' critical thinking skills, motivation, and learning outcomes. For instance, Study A1 reported questionnaire scores of 82.95% versus 73.43% and essay test scores of 79.42% versus 58.02% ($t = 6.83 > 2.04$). Study A11 showed an N-gain of 68% for learning outcomes and 11% for learning interest. Study A16, using the Kruskal-Wallis test, demonstrated a significant improvement in critical thinking through PBL with PhET simulations. In contrast, Study A13 found that learning outcomes increased significantly

with PBL assisted by Macromedia Flash ($4.43 > 1.70$). Study A15 recorded an average learning outcome gain of 0.71 compared to 0.478 in the control class, and A6 reported post-test scores rising from 54.83 to 77.83, with student motivation averaging 76.04% (high). Overall, these findings confirm that PBL positively impacts both cognitive and affective domains, although the extent of improvement varies depending on the media used and the context of implementation.

Thema 3: Implementation Context

An analysis of 24 studies indicates that the effectiveness of PBL is influenced by the media used and the comparison methods applied. Study A1 reported improved critical thinking skills among students using worksheets-based PBL compared to conventional teacher-centered learning. A11 found higher N-gain scores in both learning outcomes and student interest when PBL was supported with PowerPoint. A16 observed significant gains in critical thinking through PBL using PhET simulations compared to Discovery Learning, while A13 showed better learning outcomes with Macromedia Flash than with PowerPoint-assisted PBL. A15 reported that e-module-based PBL was more effective than textbook-based learning, and A6 highlighted increases in both motivation and learning outcomes with problem-based PBL compared to conventional student handbooks. These findings suggest that PBL is generally more effective than traditional methods, although its success depends on the chosen media and instructional design.

To provide a more comprehensive overview of the relationships among the variables studied, the instructional media used, and their effectiveness, the findings are further visualized using a bubble chart (Figure 5). In this chart, the X-axis represents the dependent variables (critical thinking, motivation, and learning outcomes), the Y-axis represents the instructional media (e.g., students' worksheets, PhET, video), the bubble size indicates the number of studies, and the bubble color reflects the reported effectiveness (average N-gain or effect size).

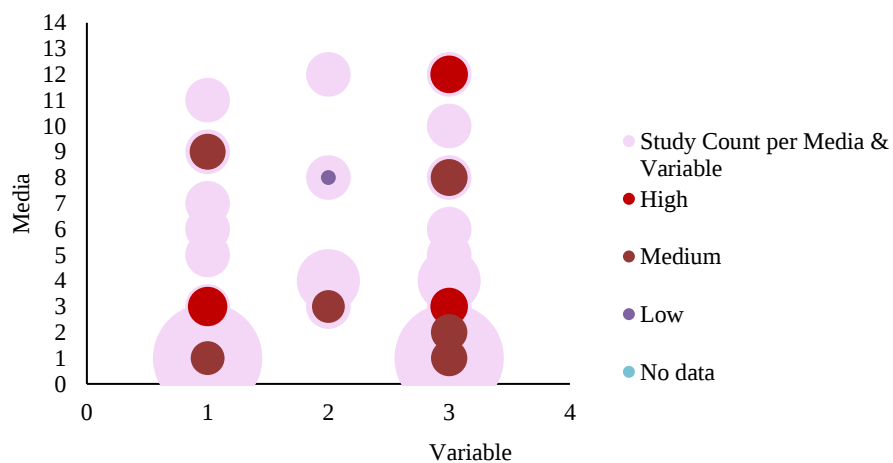


Figure 5. Visualization of N-Gain effectiveness by media and variable

On the Y-axis, media codes are employed to simplify the interpretation of the graph. For instance, code 1 represents students' worksheets, code 2 represents teaching

materials, and so forth (see Appendix G). The visualization indicates that code 1 (students' worksheets) has the largest bubbles for variables 1 (Critical Thinking) and 3 (Learning Outcomes), suggesting that students' worksheets are the most frequently studied medium. Based on the bubble chart, it is evident that students' worksheets dominate both the critical thinking and learning outcomes variables, with six studies each. The reported N-gain values fall within the medium to high range, indicating that students' worksheets are relatively consistent in enhancing both critical thinking skills and learning outcomes.

Other media, such as teaching materials, e-modules, and rotating wheels, although investigated in fewer studies, demonstrate relatively high effectiveness (N-gain 0.57–0.78). This suggests that alternative media beyond students' worksheets also hold potential for supporting effective learning. In contrast, studies employing media such as PowerPoint, Instagram, and video reveal more varied results. For example, PowerPoint appears effective in improving learning outcomes (N-gain 0.68) but less effective in fostering motivation (N-gain 0.11). Overall, learning motivation remains an underexplored variable, and its outcomes are less consistent compared to critical thinking and learning outcomes.

In conclusion, the effectiveness of learning media, as measured by N-gain, is more consistently observed in improving learning outcomes and critical thinking skills than in enhancing motivation. Students' worksheets emerge as the most frequently utilized medium with relatively stable effectiveness, while other media, though less frequently studied, also exhibit promising potential for further exploration. This visualization further highlights a research gap, as motivation is still rarely investigated across different media. This opens an avenue for future studies to explore the effectiveness of various media in enhancing learning motivation.

These findings indicate that PBL not only supports cognitive achievements but also fosters students' learning motivation. This review should be interpreted in light of contextual constraints such as students' unequal access to devices and Internet connectivity, variability in teachers' ICT readiness, and the time demands of implementing PBL. These factors may moderate the observed effects on critical thinking, motivation, and learning outcomes. Practically, schools might consider short, targeted professional development on PBL for reaction-rate instruction, curated simulation bundles (e.g., PhET), and concise explanatory videos to address abstract concepts. Additionally, they might adopt aligned formative rubrics and authentic assessments to assess critical thinking and motivation. Administrators can also plan device-sharing schedules and connectivity support to reduce access gaps. The overall analysis of the articles is presented in Appendix D, which reveals similar findings indicating that PBL tends to have a positive impact on students' cognitive and affective engagement in chemistry learning. This aligns with constructivist theory, which posits that meaningful learning occurs when students construct knowledge through direct experience and social interaction (Mir & Jain, 2015; Romdhon, Masrifah, Meena, & Suharyati, 2024; Wati et al., 2024). The Problem-Based Learning (PBL) model is considered effective in enhancing motivation, curiosity, and developing higher-order thinking skills, particularly critical thinking (Kusumawati, Soebagyo, & Nuriadin, 2022). Overall, these findings suggest that PBL is a practical approach not only in enhancing cognitive learning outcomes but also in promoting critical thinking skills and motivating students,

particularly when integrated with digital media suited to the context and needs of 21st-century students.

This study has several limitations. Potential publication bias may favor studies with positive results. Language restrictions and selected databases might have excluded relevant studies, and variations in methods, contexts, and instruments could affect consistency and generalizability. Therefore, findings should be interpreted cautiously.

▪ CONCLUSION

According to this study, PBL research on the reaction rate topic in Indonesia is mostly characterized by quantitative approaches, especially quasi-experiments. The most frequently studied variable is learning outcomes, while combined measurements of cognitive and affective aspects are still limited. Effective strategies include the use of problem-based worksheets and interactive digital media such as simulations and videos. PBL has been proven to enhance critical thinking skills, motivation, and learning outcomes, especially when applied contextually in line with the abstract nature of chemistry material.

The key message from this review is that PBL, when designed to consider the complexity and abstraction of the material, has strong potential to support deep and meaningful learning in the Indonesian context. Further research should explore: (1) How can authentic assessment be designed and integrated into PBL to capture students' cognitive and affective development in learning reaction rates? (2) In what ways can media support PBL to enhance and assess critical thinking skills and motivation simultaneously? Practically, educators in Indonesia are advised to integrate contextual problems and visual media to facilitate understanding of abstract chemical concepts. These findings are limited to the Indonesian context and cannot be generalized globally.

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