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PROBLEM-BASED LEARNING IN CHEMISTRY EDUCATION: ITS IMPACT ON UNIVERSITY STUDENTS' CRITICAL THINKING SKILLS IN INDONESIA

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Abstract

This study aims to analyze the application of *Problem-Based Learning* (PBL) in chemistry education and its impact on students' critical thinking skills in Indonesian universities. The research uses a qualitative approach with a literature study method through searching for articles on Scopus, Web of Science, ScienceDirect, ERIC, and Google Scholar published in the period 2021–2026. The literature selection process was carried out in a structured manner based on the principles of PRISMA 2020 by considering the suitability of the topic, the context of higher education, the application of PBL, and the measurement of critical thinking skills. Data were analyzed using thematic content analysis through the stages of reduction, grouping, comparison, interpretation, and synthesis. The results of the study show that PBL consistently has a positive influence on students' ability to interpret problems, analyze information, evaluate evidence, formulate inferences, provide scientific explanations, and self-regulation. The effectiveness of PBL is strongest when learning uses authentic problems, investigative activities, collaborative discussions, solution presentations, metacognitive reflection, and technology support. However, the impact of PBL is not uniform because it is influenced by initial knowledge, student motivation, group dynamics, problem quality, lecturer facilitation ability, duration of intervention, and assessment instruments used. This study concludes that PBL is a relevant approach to strengthen critical thinking skills in chemistry learning, but its implementation requires systematic planning, *scaffolding*, and evaluation. Further research is recommended to use more robust experimental designs, cross-university samples, longer durations, and standardized critical thinking instruments so that the findings have better validity and generalization. These findings provide a conceptual basis for lecturers and study program managers to design chemistry learning that is contextual, participatory, evidence-based, inclusive, sustainable, and oriented towards complex real-world problem-solving.

Keywords: chemistry education; critical thinking skills; students; problem-based learning; college.

Introduction

The ability to think critically has become one of the main competencies that must be developed through higher education because students are not only required to master knowledge, but also be able to interpret information, analyze evidence, evaluate arguments, draw conclusions, and reflect on decisions made. Academic attention to critical thinking skills continues to increase, with the teaching of critical thinking being one of the most prominent themes in contemporary educational research (Dong et al., 2023). This need is increasingly relevant in chemistry education because students must understand abstract concepts, relate macroscopic phenomena with submicroscopic and symbolic representations, and use experimental evidence to explain a phenomenon. Therefore, chemistry learning in higher education is inadequate if it is only oriented to memorizing formulas, calculation procedures, and achieving cognitive values, but must provide opportunities for students to develop scientific reasoning and critical thinking skills (Irwanto, 2023).

Ideally, chemistry education students in Indonesia are expected to be able to use their knowledge of chemistry to identify problems, build hypotheses, evaluate information, and formulate solutions based on scientific evidence. However, learning practices in higher education still face a gap between mastery of concepts and the development of high-level thinking skills. Research on chemistry education students shows that some indicators of critical thinking, such as formulating strategies, providing simple explanations, and providing follow-up explanations, can develop through active learning, but the ability to build basic skills and draw conclusions has not always reached the optimal category (Ijirana et al., 2022). Other research also shows that the development of critical thinking skills of chemistry students requires investigative activities, collaboration, writing scientific reports, and evaluating evidence that are carried out in a structured manner, not just expository material delivery (Sutiani et al., 2021; Irwanto, 2023). This condition shows that there is a gap between the competency demands of chemistry education graduates and the learning process that really trains students to think analytically, evaluatively, and reflectively.

One of the approaches that is seen as relevant to bridge this gap is *Problem-Based Learning* or PBL. This model places authentic and relatively unstructured problems as the starting point of learning so that students must identify what they already know, determine the information that is still needed, conduct investigations, develop alternative solutions, and account for the solutions chosen. In chemistry learning, contextual problems allow students to connect concepts with environmental, health, industrial, energy, and daily life issues so that knowledge is not learned separately from its use. The conceptual framework of PBL in chemistry emphasizes that the stages of problem orientation, learning organization, investigation, presentation of results, and analysis and evaluation can empower students' critical thinking skills (Miterianifa et al., 2021). The latest meta-analysis findings also show that PBL is generally more effective than conventional learning in improving critical thinking skills, with an overall effect size of 1,081 (Lu et al., 2025).

Although PBL has a strong theoretical and empirical foundation, its effectiveness in chemistry education in Indonesian universities cannot be considered uniform. A recent study on *Conceptual Problem-Based Learning* on acid-base materials among 125 prospective science teachers in two Indonesian universities found a significant increase in critical thinking skills in all groups. However, there were differences in post-secondary outcomes between classes even though the groups received the same learning intervention. These differences indicate that the success of PBL can be influenced by group dynamics, student motivation, initial knowledge, quality of problems, lecturers' facilitation skills, and the form of *scaffolding* provided during learning (Muhali & Asy'ari, 2026). Thus, the research problem is no longer just whether PBL can improve critical thinking skills, but how, under what conditions, and through what kind of learning mechanism PBL provides an optimal influence in chemistry education in Indonesian universities.

Previous research has tended to examine PBL through experiments on one course, one chemistry subject, one institution, or a specific group of students. At the same time, some of Indonesia's chemistry education research uses various terms and approaches, such as *problem-based learning*, *project-based learning*, inquiry learning, STEM, metacognition, and collaborative learning. This diversity results in scattered evidence and makes it difficult to draw specific conclusions about the core contribution of PBL to each critical thinking indicator. Cross-disciplinary meta-analyses did show a positive influence of PBL, but its effectiveness was moderated by the type of subject and teaching method so that the aggregate results did not directly explain the characteristics of PBL in chemistry learning in Indonesia (Lu et al., 2025). In addition, STEM-based research and collaborative inquiry showed positive results, but had different syntax and learning mechanisms than problem-based PBL (Ijirana et al., 2022; Irwanto, 2023). Thus, there is still a substantive gap in the form of synthesis limitations that clearly distinguish PBL from other active learning models.

Other gaps are found in the research design, measurement instruments, and implementation context. A number of studies use single-group designs, relatively limited samples, or the implementation of learning during the pandemic, so the external validity and sustainability of PBL's impact still need to be critically examined. The instruments used are also diverse, ranging from essay tests based on indicators of interpretation, analysis, evaluation, inference, explanation, and self-regulation to rubrics for practicum reports and project assessments. These differences cause the results of the study to not always be directly comparable. In addition, recent evidence suggests that improvements in groups can be substantial, but interclass outcomes remain variable due to contextual factors that are not entirely measured (Muhali & Asy'ari, 2026). Previous studies have also assessed the increase in final scores more than explaining the process of discussion, argumentation, reflection, *self-regulated learning*, and the role of lecturers that shape the development of students' critical thinking (Ijirana et al., 2022; Irwanto, 2023).

Based on these gaps, the novelty of this study lies in the preparation of a synthesis that specifically focuses on the implementation of *Problem-Based Learning* in chemistry education in Indonesian universities and its influence on students' critical thinking skills. This study not only inventoried whether PBL resulted in an increase in critical thinking skills, but also compared the characteristics of the problems used, learning syntax, chemistry, research subjects, methodological design, assessment instruments, critical thinking indicators, and contextual factors that influenced the results. The study also distinguishes problem-based PBL from *project-based learning*, inquiry, and STEM, while identifying forms of integration that truly strengthen PBL mechanisms. This approach provides *incremental newness* in the form of mapping the relationship between PBL design, student cognitive processes, and variations in critical thinking achievement that have not been comprehensively explained by individual experimental research or cross-subject meta-analysis (Lu et al., 2025; Miterianifa et al., 2021; Muhali & Asy'ari, 2026).

This study is urgent because the quality of chemistry education in higher education determines the ability of graduates to face increasingly complex scientific, educational, industrial, environmental, and social problems. For the chemistry education study program, the ability of prospective teachers also affects the quality of science learning that they will later carry out in schools. Without a strong synthesis of evidence, the implementation of PBL risks only being a procedural change in the learning plan without authentic problems, adequate facilitation, valid critical thinking assessments, and reflection on the problem-solving process. Therefore, the research entitled "Problem-Based Learning in Chemistry Education: Its Impact on University Students' Critical Thinking Skills in Indonesia" aims to analyze the implementation of PBL in chemistry education in Indonesian universities, evaluate its influence on various indicators of critical thinking ability, identify supporting and inhibiting factors of its effectiveness, and formulate recommendations for the development of chemistry learning and research further (Irwanto, 2023; Lu et al., 2025; Muhali & Asy'ari, 2026).

Research Methods

This study uses a qualitative approach with a library *research* method through a structured literature review. This method is used to identify, select, evaluate, and synthesize research results regarding the application of *Problem-Based Learning* (PBL) in chemistry education and its influence on students' critical thinking skills in Indonesian universities. Literature searches were conducted through the Scopus, Web of Science, ScienceDirect, ERIC, and Google Scholar databases with publication restrictions in the period January 2021–July 2026. The keywords used included "problem-based learning", "chemistry education", "critical thinking skills", "university students", "higher education", and "Indonesia", which were combined using Boolean AND and OR operators. The process of searching and selecting articles follows the principles of PRISMA 2020 which includes the stages of identification, screening, feasibility checks, and determination of articles included in the analysis. The approach is used to improve the transparency, traceability, and repeatability of the literature review process (Carrera-Rivera et al., 2022; Page et al., 2021).

The research inclusion criteria include journal articles that have gone through *a peer review process*, are available in full text, are published in Indonesian or English, discuss the application of PBL to chemistry learning in Indonesian universities, and measure the critical thinking skills of students or prospective chemistry teachers. Duplicate articles, proceedings without a clear review process, theses, theses, dissertations, conceptual articles without research results, research at the elementary or secondary school level, and studies that do not specifically address chemistry learning are excluded from the analysis. Data from the selected articles were extracted into a matrix containing the author's name, year of publication, research location, number and characteristics of participants, chemical material, research design, form of PBL implementation, measurement instruments, critical thinking indicators, and research results. The data was then analyzed using thematic content analysis through the process of reduction, grouping, comparison, interpretation, and synthesis to find patterns of effectiveness, supporting factors, implementation constraints, and research gaps. Reporting at each stage is carried out systematically so that the relationship between the research questions, study characteristics, selection process, and synthesis results can be explained transparently (Sauer & Seuring, 2023).

Results and Discussion

The results of the literature synthesis show that the application *of Problem-Based Learning* has a positive influence on students' critical thinking skills in chemistry learning and fields of science related to chemistry. Students who participate in problem-based learning tend to obtain higher critical thinking achievements than students who participate in conventional learning. Research on Indonesian chemistry teacher candidates shows that PBL has a significant effect on critical thinking skills and scientific attitudes, with a contribution of 28% to the model. The findings were corroborated by a meta-analysis of 25 studies with a total of 1,846 participants that resulted in a randomized model effect size of 1.081, a 95% confidence interval [0.874–1.288], and a p< value of 0.05. At the university level, the measure of the effect of PBL on critical thinking skills is also relatively high, which is 0.975. These results show that problem-based learning is generally more effective than lecture-centered learning in developing students' ability to analyze information, evaluate evidence, and make rational decisions (Lu et al., 2025; Wahyudiati, 2022).

The improvement of critical thinking skills through PBL can be seen in several indicators, especially the ability to interpret problems, analyze relationships between concepts, evaluate information, draw conclusions, provide explanations, and self-regulation. Muhali and Asy'ari's (2026) research on 125 prospective science teachers from two Indonesian universities on acid-base materials showed a significant increase in all groups after the implementation of *Conceptual Problem-Based Learning*, with a p value of < 0.001. The *normalized gain* value was in the medium category, while the size of the effect in the group was very large with a Cohen's *d* value between 2.27 and 5.21. These achievements show that the integration of structured inquiry and conceptual reinforcement in PBL helps students develop critical thinking skills more comprehensively, not just increasing mastery of chemistry problem-solving procedures (Muhali & Asy'ari, 2026).

The results of the study also show that the use of authentic, contextualized chemical problems is an important characteristic of PBL's effectiveness. Issues related to environmental pollution, chemical safety, health, energy, food, acid-base reactions, and the use of chemical products in daily life encourage students to connect theoretical concepts with real conditions. Through the stages of problem orientation, organizing learning activities, individual and group investigations, presenting solutions, and evaluating the problem-solving process, students have the opportunity to ask questions, analyze arguments, examine observations, identify assumptions, and determine the most rational course of action. Thus, authentic problems not only serve as material illustrations, but also trigger intellectual activity that demands the use of evidence and chemical concepts in generating solutions (Miterianifa et al., 2021).

The effectiveness of PBL also increases when its implementation is supported by group collaboration, investigation activities, argumentative discussions, presentation of results, learning technology, and reflection. The application of PBL integrated with *blended learning* in biochemistry courses increased the percentage of students' critical thinking skills from 52.29% in the first cycle to 64.43% in the second cycle. Face-to-face learning combined with online discussion forums provides a wider space for students to access information sources, exchange opinions, formulate arguments, and evaluate group solutions. Findings on STEM project-based chemistry learning and metacognitive skills also showed that the ability to formulate strategies, provide simple explanations, and provide follow-up explanations were in the excellent category, while the ability to build basic skills and draw conclusions was in the good category. These results confirm the importance of social, metacognitive, and technological activities in supporting the development of students' critical thinking (Ijirana et al., 2022; Yennita & Zukmadini, 2021).

Although most studies have shown positive results, the effectiveness of PBL is not uniform across classrooms and educational contexts. The *Conceptual Problem-Based Learning* study found significant differences in post-traumatic outcomes between several groups even though all groups received the same treatment. These differences indicate that student achievement can be influenced by initial knowledge, motivation, group dynamics, lecturers' ability to provide facilitation, and the level of conceptual support students receive. The meta-analysis also found a fairly high heterogeneity between publications, with an I^2 value of 69.935%. In addition, some studies still use limited samples, single-group designs, self-developed instruments, or relatively short duration of interventions. This condition causes the research results to not be fully generalized to all chemistry study programs and universities in Indonesia (Lu et al., 2025; Muhali & Asy'ari, 2026).

Discussion

The findings of the study show that the influence of PBL on critical thinking skills comes from changes in students' positions in the learning process. In conventional learning, students generally accept concepts and procedures that have been prepared by lecturers, while in PBL students must determine problems, identify learning needs, seek information, assess the reliability of evidence, develop solutions, and defend their arguments. Each of these stages is related to critical thinking indicators. Problem-orientation, training, interpretation and identification of problems; Investigation training the analysis and evaluation of evidence; group discussions practice argumentation and openness to other points of view; Meanwhile, the presentation and evaluation of solutions train inference, explanation, and self-regulation. This mechanism explains why PBL produces a high effect size compared to conventional methods. However, PBL is not enough to be done by giving questions at the beginning of the lecture. Problems must be open, relevant, challenging, and require the application of some chemical concepts in order to create cognitive conflicts and encourage in-depth inquiry (Lu et al., 2025; Miterianifa et al., 2021).

The effectiveness of PBL in Indonesian chemistry education also depends on the quality of implementation and learning support provided by lecturers. Students who do not have a conceptual understanding and independent learning experience can experience difficulties when directly confronted with complex chemistry problems. Therefore, lecturers need to provide *scaffolding* in the form of triggering questions, concept maps, selected reading sources, research guides, argumentation rubrics, and formative feedback without taking over the student's problem-solving process. Laboratory activities, collaboration, digital technology, and metacognitive reflection also need to be integrated according to learning objectives. Further research needs to use a stronger experimental design, control groups, cross-university samples, longer duration of interventions, and standardized critical thinking instruments. Future studies also need to analyze the influence of initial knowledge, motivation, problem quality, lecturer facilitation skills, and group dynamics so that the conditions that make PBL effective for various characteristics of Indonesian chemistry students can be identified (Irwanto, 2023; Muhali & Asy'ari, 2026).

Conclusion

Based on the results of the literature review, the application of *Problem-Based Learning* in chemistry education in Indonesian universities has a positive influence on improving students' critical thinking skills. This model is able to encourage students to interpret problems, analyze relationships between concepts, evaluate evidence, draw conclusions, provide scientific explanations, and reflect on the problem-solving process. This effectiveness mainly arises because PBL places students as active subjects who must identify problems, seek information, conduct investigations, discuss, develop alternative solutions, and account for decisions based on concepts and chemical evidence. The use of authentic and contextual problems also helps students connect abstract chemical concepts with environmental, health, energy, food, and everyday life issues.

However, the effectiveness of PBL is not always uniform in every class and institution. The success is influenced by the quality of the problem, initial knowledge and motivation of students, group dynamics, availability of learning resources, learning duration, and the ability of lecturers to provide facilitation and *scaffolding*. Therefore, PBL needs to be implemented through systematic planning, the use of relevant and challenging problems, targeted investigation activities, argumentative discussions, the use of technology, and valid critical thinking assessments. Further research needs to involve cross-university samples, control groups, longer intervention durations, and standardized instruments in order to obtain stronger evidence on the effectiveness of PBL in improving the critical thinking skills of chemistry students in Indonesia.

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