

The Effectiveness of Problem-Based Learning Integrated with the STEAM-LABIRIN Approach in Developing Students' Conceptual Understanding and Critical Thinking Skills

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Abstract: *Developing students' conceptual understanding and critical thinking skills is essential in twenty-first-century chemistry learning, yet fostering both competencies simultaneously remains a persistent challenge in classroom practice. This study aimed to examine the effectiveness of Problem-Based Learning (PBL) integrated with the STEAM-LABIRIN approach in developing students' conceptual understanding and critical thinking skills in acid-base chemistry learning. A quasi-experimental method with a non-equivalent control group design was employed, involving 68 eleventh-grade students. Data were analyzed using normalized gain (N-gain) scores, Multivariate Analysis of Variance (MANOVA), and Tests of Between-Subjects Effects. The findings revealed that PBL integrated with the STEAM-LABIRIN approach had a statistically significant simultaneous effect on students' conceptual understanding and critical thinking skills. When examined individually, the approach significantly improved critical thinking skills, whereas its effect on conceptual understanding did not differ significantly from that of the control group. These findings indicate that PBL integrated with the STEAM-LABIRIN approach is particularly effective for fostering critical thinking skills and holds potential for supporting the development of conceptual understanding in chemistry education.*

Keywords: *Problem-Based Learning, STEAM-LABIRIN, conceptual understanding, critical thinking skills, chemistry learning.*

Abstrak: *Maksimal Mengembangkan pemahaman konseptual dan keterampilan berpikir kritis siswa sangat penting dalam pembelajaran kimia abad ke-21, namun menumbuhkan kedua kompetensi tersebut secara bersamaan tetap menjadi tantangan yang terus-menerus dalam praktik pembelajaran di kelas. Penelitian ini bertujuan untuk menguji keefektifan Pembelajaran Berbasis Masalah (PBL) yang diintegrasikan dengan pendekatan STEAM-LABIRIN dalam mengembangkan pemahaman konseptual dan keterampilan berpikir kritis siswa dalam pembelajaran kimia asam-basa. Metode kuasi-eksperimental dengan desain kelompok kontrol non-ekuivalen digunakan, yang melibatkan 68 siswa kelas sebelas. Data dianalisis menggunakan skor normalized gain (N-gain), Analisis Variansi Multivariat (MANOVA), dan Uji Efek Antar-Subjek. Temuan menunjukkan bahwa PBL yang diintegrasikan dengan pendekatan STEAM-LABIRIN memiliki efek simultan yang signifikan secara statistik terhadap pemahaman konseptual dan keterampilan berpikir kritis siswa. Ketika ditinjau secara terpisah, pendekatan ini secara signifikan meningkatkan keterampilan berpikir kritis, sedangkan pengaruhnya terhadap pemahaman konseptual tidak berbeda secara signifikan dengan kelompok kontrol. Temuan ini menunjukkan bahwa PBL yang diintegrasikan dengan pendekatan STEAM-LABIRIN sangat efektif*

dalam menumbuhkan keterampilan berpikir kritis dan memiliki potensi untuk mendukung pengembangan pemahaman konseptual dalam pendidikan kimia.

Kata Kunci: Pembelajaran Berbasis Masalah; STEAM-LABIRIN; pemahaman konseptual; keterampilan berpikir kritis; pembelajaran kimia.

Introduction

The rapid advancement of science and technology in the twenty-first century, together with the transition toward Society 5.0, requires students to possess competencies that extend well beyond mere content knowledge. Twenty-first-century competencies commonly referred to as the 4C skills of critical thinking, creativity, communication, and collaboration have become indispensable for addressing increasingly complex global challenges. Learning environments therefore need to be designed to be contextual and student-centered, and to foster competencies relevant to future societal needs (UNESCO, 2021; OECD, 2023; Partono et al., 2021; Nastiti & Ni'mal Abdu, 2020).

Chemistry is a scientific discipline characterized by abstract, complex, and interconnected concepts. Students are expected to understand and relate macroscopic, microscopic, and symbolic representations when explaining chemical phenomena, and difficulties in connecting these representations often lead to misconceptions that hinder conceptual understanding. Chemistry learning further requires higher-order thinking skills to analyze conceptual relationships and to apply scientific knowledge to real-world contexts (Gilbert & Treagust, 2009; Nurfatonah et al., 2024; Johnstone, 1991).

Conceptual understanding and critical thinking skills are two fundamental competencies that need to be developed in chemistry education. Conceptual understanding enables students to explain, interpret, and apply scientific concepts meaningfully, whereas critical thinking skills support students in analyzing information, evaluating arguments, and making evidence-based decisions components that Facione (2020) identifies as interpretation, analysis, evaluation, inference, and explanation. Previous studies have demonstrated that both competencies contribute significantly to students' academic achievement and their readiness to solve real-world problems (Nurfatonah et al., 2024; Facione, 2020; Ekayanti et al., 2025).

Despite their importance, international assessments indicate that Indonesian students' higher-order thinking skills remain relatively low. The Programme for International Student Assessment (PISA) 2022 reported that Indonesian students' scientific literacy performance remains below the OECD average (OECD, 2023). These findings highlight the need for innovative instructional approaches that promote meaningful and contextual learning experiences capable of simultaneously developing conceptual understanding and critical thinking skills.

Problem-Based Learning (PBL) has been widely recognized as an effective instructional model for fostering conceptual understanding and critical thinking skills. As a model in which students learn through authentic problem-solving, investigation, discussion, and reflection (Arends, 2012), PBL provides opportunities for students to actively construct knowledge and develop higher-order thinking. Previous studies report that PBL improves conceptual understanding, critical thinking skills, learning outcomes, and student engagement in chemistry learning (Uliyandari et al., 2021; Delfiza & Fuadiyah, 2024; Wulandari et al., 2026; Hasanah, 2023).

In addition to instructional models, integrating the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach has shown considerable potential for promoting twenty-first-century competencies. STEAM encourages multidisciplinary thinking and enables students to develop creativity, collaboration, and critical thinking while solving authentic

problems. Several studies have demonstrated that integrating STEAM through Problem-Based Learning and STEM-PBL positively affects conceptual understanding, critical thinking skills, learning motivation, and other twenty-first-century competencies (Ozkan & Topsakal, 2020; Ekayanti et al., 2025; Nurhasnah et al., 2023; Monika et al., 2023; Sakti, 2025).

Although numerous studies have investigated the effectiveness of PBL and STEAM integration, most have focused on developing only one or two student competencies and have not incorporated instructional approaches that provide enjoyable, interactive, and meaningful learning experiences. The LABIRIN approach which emphasizes enjoyable (*Seru*), interactive (*Interaktif*), and unique (*Unik*) learning experiences offers opportunities to build more holistic learning environments that support critical thinking and other twenty-first-century competencies. The integration of LABIRIN and STEAM within the Problem-Based Learning framework has likewise demonstrated potential for promoting student-centered learning and developing twenty-first-century skills (Sorry et al., 2025; Subekti et al., 2026).

However, research investigating the effectiveness of integrating Problem-Based Learning with the STEAM-LABIRIN approach in chemistry education remains limited. Previous studies have generally examined the effects of PBL or STEAM separately, whereas studies that integrate both approaches through STEAM-LABIRIN to simultaneously develop conceptual understanding and critical thinking skills in chemistry learning are still scarce. This study addresses that gap by investigating the effectiveness of PBL integrated with the STEAM-LABIRIN approach in developing students' conceptual understanding and critical thinking skills in acid-base chemistry learning, based on the Chemistry Learning Outcomes (Phase F) of the Merdeka Curriculum (Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi [Kemendikbudristek], 2022).

The novelty of this study lies in its simultaneous integration of three instructional dimensions that prior research has generally examined separately: the problem-solving structure of PBL, the multidisciplinary framework of STEAM, and the affective-engagement principles of the LABIRIN approach (enjoyable, interactive, and unique learning experiences). By combining these dimensions within a single instructional design and evaluating their joint and individual effects through a multivariate analysis on two interrelated learning outcomes conceptual understanding and critical thinking skills this study offers empirical evidence on how a holistic, student-centered, and engagement-oriented model can be implemented in acid-base chemistry learning under the Merdeka Curriculum. This integrative and simultaneous-effect perspective distinguishes the present study from previous research and contributes new empirical insight to the literature on innovative chemistry instruction.

Methods

Bagian This study employed a quasi-experimental method using a non-equivalent control group design to examine the effectiveness of Problem-Based Learning (PBL) integrated with the STEAM-LABIRIN approach in developing students' conceptual understanding and critical thinking skills in chemistry learning. This design was selected because random assignment of intact classes was not feasible in the school setting, consistent with common practice in educational quasi-experimental research (Creswell & Creswell, 2018; Fraenkel et al., 2019). The study was conducted on the topic of acid-base solutions, based on the Chemistry Learning Outcomes (Phase F) of the Merdeka Curriculum. The experimental class received instruction using PBL integrated with the STEAM-LABIRIN approach, whereas the control class was taught using PBL without the STEAM-LABIRIN approach.

The participants consisted of 68 eleventh-grade students of SMA Santa Angela Bandung in the 2025/2026 academic year, selected through purposive sampling (Sugiyono, 2023). Class

XI-7 was assigned as the experimental class, and Class XI-8 served as the control class. The research instruments included conceptual understanding and critical thinking skills tests administered before and after the instructional intervention, and all instruments were validated by experts prior to implementation. The instructional materials used in this study included teaching modules, student worksheets, and learning media developed based on the characteristics of the STEAM-LABIRIN approach and the learning objectives of acid-base chemistry.

Data were analyzed using descriptive and inferential statistical methods. Students' learning improvement was measured using normalized gain (N-gain) scores. Prior to hypothesis testing, normality and homogeneity tests were conducted to ensure that statistical assumptions were satisfied. The effects of the instructional model on students' conceptual understanding and critical thinking skills were then analyzed using Multivariate Analysis of Variance (MANOVA), and the magnitude of the treatment effects was determined using Partial Eta Squared values obtained from the MANOVA results.

Result and Discussion

Effectiveness of PBL Integrated with the STEAM-LABIRIN Approach on Students' Conceptual Understanding

The normalized gain (N-gain) analysis showed that students' conceptual understanding improved at a moderate level in both classes, with the experimental class achieving a slightly higher mean N-gain score than the control class.

Presentasi Data: Mulailah dengan menyajikan data hasil penelitian Anda yang dapat berupa tabel, grafik, diagram, atau bahkan kutipan data yang relevan. Pastikan untuk memberi judul pada setiap elemen visual yang Anda gunakan dan berikan label yang jelas seperti di bawah ini.

Table 1. N-Gain of Students' Conceptual Understanding

Class	Mean N-gain Score	Category
Experimental	0.387	Moderate
Control	0.355	Moderate

Table 1 shows that the experimental class demonstrated a slightly greater improvement in conceptual understanding than the control class, although both classes were categorized as moderate. However, the MANOVA results indicated that PBL integrated with the STEAM-LABIRIN approach did not significantly affect students' conceptual understanding (Sig. = 0.436 > 0.05), with a Partial Eta Squared value of 0.009, indicating a small effect size.

These findings suggest that Problem-Based Learning implemented in both classes effectively facilitated students' conceptual knowledge construction, so that the differences in instructional treatment were insufficient to produce statistically significant differences in conceptual understanding. In chemistry learning, conceptual understanding involves more than memorizing scientific concepts; it requires students to connect macroscopic, microscopic, and symbolic representations when explaining chemical phenomena (Gilbert & Treagust, 2009; Johnstone, 1991). Meaningful learning experiences are therefore essential for enabling students to construct conceptual knowledge effectively.

Furthermore, the STEAM-LABIRIN approach provided students with more complex and multidisciplinary learning experiences, including individual problem analysis, collaborative discussions, laboratory activities, infographic poster design, and educational games related to acid-base concepts. While these activities enriched students' learning experiences, they also divided instructional time among multiple tasks, which may have limited opportunities for deeper conceptual exploration. These findings are consistent with previous studies reporting that PBL

positively contributes to conceptual understanding through contextual and student-centered learning environments (Uliyandari et al., 2021; Wulandari et al., 2026; Hasanah, 2023). However, integrating STEAM-LABIRIN into PBL does not necessarily guarantee significantly higher conceptual understanding when both groups already receive problem-based instruction.

Effectiveness of PBL Integrated with the STEAM-LABIRIN Approach on Students' Critical Thinking Skills

Students in the experimental class demonstrated greater improvements in critical thinking skills than those in the control class.

Table 2. N-Gain of Students' Critical Thinking Skills

Class	Mean N-gain Score	Category
Experimental	0.550	Moderate
Control	0.429	Moderate

Table 2 shows that students in the experimental class achieved greater improvement in critical thinking skills than those in the control class, although both groups demonstrated moderate levels of improvement. The MANOVA analysis revealed a statistically significant difference between the experimental and control classes ($\text{Sig.} = 0.000 < 0.05$), with a Partial Eta Squared value of 0.214, indicating a large effect size. These findings demonstrate that integrating STEAM-LABIRIN into PBL is particularly effective in fostering higher-order thinking skills.

The improvement in critical thinking skills is likely attributable to the systematic design of learning activities that encouraged students to analyze information, evaluate evidence, and make evidence-based decisions. Students were required to individually analyze contextual problems before participating in collaborative discussions and laboratory investigations. Subsequent activities including laboratory experiments, data analysis, and infographic poster development provided opportunities for students to evaluate information, formulate conclusions, and communicate their scientific reasoning. These activities align closely with Facione's (2020) critical thinking components of interpretation, analysis, evaluation, inference, and explanation.

Moreover, the multidisciplinary nature of the STEAM approach enabled students to engage with authentic problems from multiple perspectives: Science facilitated conceptual understanding, Technology supported information literacy, Engineering promoted solution design, Arts encouraged creative scientific communication, and Mathematics strengthened quantitative reasoning (Ozkan & Topsakal, 2020; Ekayanti et al., 2025; Nurhasnah et al., 2023; Monika et al., 2023). These findings support previous studies indicating that both PBL and STEAM approaches contribute significantly to the development of students' critical thinking skills (Delfiza & Fuadiyah, 2024; Hasanah, 2023; Nurhasnah et al., 2023; Monika et al., 2023). The LABIRIN approach further enhances student engagement by creating enjoyable, interactive, and unique learning experiences that promote deeper cognitive involvement throughout the problem-solving process (Sorry et al., 2025; Subekti et al., 2026).

Multivariate Effects of PBL Integrated with the STEAM-LABIRIN Approach and Its Implications for Chemistry Learning

The MANOVA results revealed different effects on each dependent variable as well as a significant simultaneous effect of the instructional treatment.

Table 3. MANOVA Results

Variable	Sig.	Partial Eta Squared	Effect Size Category
Conceptual Understanding	0.436	0.009	Small
Critical Thinking Skills	0.000	0.214	Large
Simultaneous Effect	0.000	0.214	Large

Table 3 shows that PBL integrated with the STEAM-LABIRIN approach had a significant simultaneous effect on students' conceptual understanding and critical thinking skills, with a large effect size. Interestingly, although conceptual understanding did not differ significantly between groups, the substantial improvement in critical thinking skills contributed considerably to the significant multivariate findings. These results indicate that the effectiveness of instructional models should not be evaluated solely on the basis of a single learning outcome, but rather on their capacity to simultaneously develop multiple interconnected competencies.

In chemistry education, conceptual understanding and critical thinking skills complement one another. Students are expected not only to understand scientific concepts but also to apply them when analyzing chemical phenomena, solving contextual problems, and making evidence-based decisions. The findings imply that integrating Problem-Based Learning, STEAM, and the LABIRIN approach offers a promising alternative for implementing the Merdeka Curriculum and promoting twenty-first-century competencies in chemistry education. By providing active, contextual, and student-centered learning experiences, the STEAM-LABIRIN approach supports the development of higher-order thinking skills while simultaneously contributing to conceptual understanding.

Overall, this study demonstrates that PBL integrated with the STEAM-LABIRIN approach is particularly effective in fostering critical thinking skills and contributes significantly to the simultaneous development of conceptual understanding and critical thinking skills. These findings highlight its potential as an innovative instructional approach for twenty-first-century chemistry learning.

Conclusion

This study aimed to investigate the effectiveness of Problem-Based Learning (PBL) integrated with the STEAM-LABIRIN approach in developing students' conceptual understanding and critical thinking skills in acid-base chemistry learning. Several conclusions can be drawn from the findings.

PBL integrated with the STEAM-LABIRIN approach improved students' conceptual understanding and critical thinking skills at a moderate level, as reflected by the N-gain scores. The approach had a statistically significant and large effect on students' critical thinking skills (Sig. = 0.000; Partial Eta Squared = 0.214), whereas its effect on conceptual understanding was not statistically significant (Sig. = 0.436; Partial Eta Squared = 0.009). Nevertheless, the multivariate analysis showed a significant and large simultaneous effect of the treatment on both competencies together.

These findings indicate that integrating PBL, STEAM, and the LABIRIN approach is particularly effective in promoting higher-order thinking skills through contextual, collaborative, and multidisciplinary learning activities. The results also highlight the importance of evaluating instructional effectiveness from multiple learning outcomes simultaneously, since chemistry learning should support not only conceptual understanding but also interconnected twenty-first-century competencies. For classroom practice, the findings suggest that teachers can adopt STEAM-LABIRIN-enriched PBL as an alternative model for implementing the Merdeka Curriculum, particularly when the instructional goal emphasizes higher-order thinking rather than content mastery alone.

This study has several limitations that should be considered when interpreting its findings. First, the sample was limited to 68 eleventh-grade students from a single school, which restricts the generalizability of the results to other schools, grade levels, or regions. Second, the study focused solely on the topic of acid-base solutions within a relatively short instructional period, so the long-term retention of conceptual understanding and critical thinking skills could not be assessed. Third, the use of a non-equivalent control group design, while methodologically appropriate for classroom-based research, does not eliminate all threats to internal validity associated with the absence of random assignment. Finally, the non-significant effect on conceptual understanding may partly reflect the divided instructional time inherent in the multidisciplinary STEAM-LABIRIN activities, a factor that was not directly measured in this study.

Future studies are recommended to apply the PBL-STEAM-LABIRIN approach to other chemistry topics and across broader and more diverse samples, and to provide longer instructional durations to further optimize students' conceptual understanding alongside their higher-order thinking skills. Subsequent research may also examine how instructional time allocation among STEAM-LABIRIN activities can be optimized to strengthen conceptual gains without compromising the development of critical thinking, and may explore qualitative approaches to better understand students' cognitive processes during STEAM-LABIRIN-based PBL implementation. Overall, the STEAM-LABIRIN approach offers a promising alternative for implementing student-centered chemistry learning aligned with the Merdeka Curriculum.

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