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Synergistic Effects of Problem-Based Learning and VAK Learning Styles on Critical Thinking and Self-Efficacy in High School Chemistry

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Abstract: This study investigated the impact of learning styles and learning models on students' critical thinking skills and self-efficacy in chemistry, with a focus on atomic structure and fundamental chemical laws. The research design employed was a quasi-experimental 2×3 factorial design with 108 tenth-grade high school students. The independent variables were the learning model (Problem-Based Learning/PBL and direct instruction) and learning styles (visual, auditory, kinesthetic). In contrast, the dependent variables were critical thinking skills and self-efficacy. Data were collected using the VAK learning style inventory, a validated critical thinking test, and a self-efficacy questionnaire. Data analysis employed two-way ANOVA followed by Tukey HSD post hoc tests. The results revealed that both learning models and learning styles significantly impacted students' critical thinking skills. Students with kinesthetic learning styles performed better in critical thinking than those with visual or auditory learning styles. However, learning styles did not significantly influence self-efficacy, suggesting that students' confidence is more strongly shaped by mastery experiences, positive feedback, and social support. The PBL model significantly enhanced both critical thinking skills and self-efficacy, highlighting the value of collaborative and contextual learning activities in developing higher-order thinking and motivation. A significant interaction was observed between learning styles and learning models, with a notable benefit for visual and kinesthetic learners in terms of self-efficacy. This study acknowledges the fundamental limitation of the VAK framework, as empirical evidence for its validity remains weak; hence, interpretations should be made cautiously. Theoretically, the findings support Bandura's social cognitive theory, which emphasizes that self-efficacy and learning outcomes are shaped through active engagement and authentic experiences. Practically, this study suggests designing adaptive PBL approaches aligned with learners' diverse characteristics to optimize both motivation and confidence in chemistry learning.

Keywords: learning styles, problem-based learning (PBL), critical thinking skills, self-efficacy.

▪ INTRODUCTION

One of the essential components of 21st-century education is the development of critical thinking skills, which are vital for success in the era of globalization (Çavuş et al., 2025). Critical thinking skills are not only a key component of 21st-century education but also a fundamental support for academic and professional achievement. In addition, critical thinking is a crucial goal in science education, particularly in chemistry learning (Shaw et al., 2020; García-Carmona, 2025; Santos-Meneses et al., 2023; Zhang et al., 2023). The development of students' critical thinking skills is a focus of global curricula, especially in Indonesia, because it is considered very important for citizens in facing significant global evolutions, including the era of the Industrial Revolution 4.0 and 5.0 (Elaish et al., 2023), and the evolution of artificial intelligence (Walter, 2024). Critical

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thinking skills are not only a strong predictor of academic achievement but also of success in life (Bellaera et al., 2021).

Critical thinking in science learning serves two fundamental roles: first, as a means of generating ideas for the application of science, technology, and scientific innovation; second, in relation to the implementation of science or scientific procedures, as well as teaching practices and the understanding of science (Yacoubian, 2015). The ability to think precisely and methodically, utilizing concepts of logic and scientific reasoning, is a standard definition of critical thinking skills (Leest & Wolbers, 2021). Because they enable pupils to conduct in-depth analysis required to solve problems, these abilities are essential for effective problem-solving. As a result, teachers are urged to design lessons that help pupils advance their scientific knowledge, including in chemistry. Students would greatly benefit from chemistry instruction that fosters critical thinking while helping them understand chemical principles that are often regarded as challenging, particularly in their everyday applications. Students often view chemical concepts, such as understanding matter, changes in matter, symbols, and chemical modeling, as abstract, despite their significant relevance to daily life (Kohen et al., 2020). This calls for greater effort to cultivate critical thinking abilities, encompassing both theoretical mastery and the capacity to apply them to real-world situations.

Although considerable effort has been made to improve critical thinking in Indonesia, numerous problems persist, highlighting many students' poor critical thinking skills. For instance, Hadisaputra et al. (2020) found that only a small percentage of students engaged with the questions, that some students were inactive during group projects, and that students were not proactive in raising issues during learning. Students were consequently unable to provide answers to the problems they encountered. This circumstance may indicate that pupils' critical thinking skills are still underdeveloped. Additionally, studies by Everett et al. (2018) and Ramos (2018) demonstrate that a lack of teacher attention to critical thinking has prevented students' critical thinking abilities from reaching full potential. Most students are still at a low level in their thinking skills.

There are several opinions on critical thinking, including Ennis (1989), who compiled critical thinking indicators comprising five aspects: providing basic explanations, building basic skills, drawing conclusions, making further explanations, and employing strategies and tactics. In addition, Facione (2011) compiled critical thinking indicators, namely: Interpretation, analysis, conclusion, evaluation, explanation, and self-regulation. Furthermore, critical thinking indicators, as measured by the Watson-Glaser Critical Thinking Appraisal (WGCTA). WGCTA has been identified as a test that pioneered the measurement of critical thinking (Grimard & Wagner, 1981). These indicators include (a) defining the problem; (b) selecting information relevant to the problem solution; (c) recognizing stated and unstated assumptions; (d) formulating and selecting relevant and promising hypotheses; and (e) drawing valid conclusions and assessing the validity of the conclusions. These three critical thinking indicators, synthesized by Sugrah et al. (2023), will be used to measure critical thinking skills.

Critical thinking skills, essential for the 21st century, are closely linked to student self-efficacy. Students with high self-efficacy will have strong confidence in the learning process and greater courage to take risks in creating innovative ideas (Aghajani & Gholamrezapour, 2019). Self-efficacy is closely related to learning motivation, as students who believe in their abilities tend to demonstrate high motivation and perseverance in facing various academic challenges (Ferrell & Barbera, 2015; Prabandaru et al., 2020; Uitto, 2014). Students' confidence in their own abilities will be a key component of their academic success, as those who believe in their abilities will seek and utilize various effective learning strategies to better overcome the problems or difficulties they face (Samsuddin et al., 2020). Self-efficacy is also related to students' emotions. Students who manage their emotions and stress when solving problems tend to have high self-efficacy (Odedokun et al., 2023). In contrast, those with low self-efficacy often feel burdened and stressed when facing challenges or complex assignments, which negatively affects their engagement and commitment to learning. As a result, strengthening self-efficacy is a crucial aspect of increasing student motivation and academic achievement. Individuals who lack confidence in their abilities tend to exhibit decreased self-confidence (Shahali et al., 2015).

Additionally, students' learning styles play a crucial role in enhancing critical thinking skills and self-efficacy, as they influence how students perceive, process, and engage with learning materials (D. Costa et al., 2020). The learning styles that have been developed also differ; for example, the VAK learning style model describes learning styles based on learner perception (Faisal, 2018; Ocepek et al., 2013), the Hemisoheric dominance model and learning styles describe learning styles based on learner's hemisphere (brain) preferences (Weisi & Khaksar, 2015), the Kolb learning style model describes learning styles based on learner experience (Saifi et al., 2024), and the Rancourt learning style model describes learning styles based on the learner's psycho-epistemological mode (Ocepek et al., 2013). However, the goal of this study is to identify findings that are impacted by VAK learning styles. Visual (V), auditory (A), and kinesthetic (K) are the acronyms for the information-gathering processes that humans use for successful learning and growth (Faisal, 2018; Ocepek et al., 2013).

Specifically, it has been suggested that aligning instructional delivery with students' dominant VAK learning styles can enhance learning experiences, thereby strengthening their confidence in their capacity to succeed in academic tasks (Baherimoghadam et al., 2021). Conversely, a mismatch between these factors can lead to decreased self-confidence and perceived competence, which, in turn, can impact academic performance and overall learning effectiveness (Azlan et al., 2025; Liang et al., 2023). This theoretical relationship underscores the idea that students with higher self-efficacy are more likely to achieve academic success, as their confidence in their abilities directly influences their persistence and engagement in learning tasks (Liang et al., 2023). This intrinsic link suggests that developing an educational environment that accommodates diverse learning styles can implicitly strengthen students' self-efficacy beliefs, thereby improving academic outcomes. For example, students with high self-efficacy tend to master tasks more effectively and persist in the face of challenges. In contrast, individuals with low self-efficacy tend to abandon tasks prematurely, which can lead to poorer academic performance (Laitinen et al., 2024).

Problem-based learning (PBL) fosters critical thinking skills and builds self-efficacy. PBL prioritizes collaborative, student-centered learning and engages students in authentic problem-solving. This approach promotes critical thinking, group collaboration, and the development of more comprehensive problem-solving skills in students (Fakour & Imani, 2025; Velly, 2021). According to research, PBL can enhance students' critical thinking abilities by streamlining methodical group work procedures, enabling them to continuously refine and advance their thinking abilities (Prabandaru et al., 2020). However, prior studies assessing critical thinking in PBL have produced conflicting findings; some have found a positive correlation between PBL and critical thinking, while others have found the opposite (Gao et al., 2024; Sharma et al., 2023). As a result, PBL requires instructional innovation, such as considering pupils' learning preferences. In chemistry, differentiated learning based on the VAK learning styles has been shown to improve students' conceptual understanding and critical thinking. However, it poses implementation challenges in active learning contexts such as PBL (Hariyanto et al., 2025). Empirical evidence also suggests that learning styles are related to students' science achievement (Cimermanová, 2018; Gelata et al., 2024) and critical thinking performance (Darmayanti et al., 2022).

Challenges in chemistry learning include accommodating students' diverse learning styles while creating an environment that supports the development of critical thinking skills and fosters students' self-efficacy. Students' learning styles are undeniably diverse, yet current educational approaches consistently fail to address this reality. By actively embracing flexible learning strategies tailored to each student's unique needs, educators can empower the development of critical thinking skills and foster greater self-efficacy. Based on this background, this study aims to determine the influence of learning styles and learning models on students' critical thinking skills and self-efficacy.

▪ METHOD

Research Design

This study is an experimental study in which one or more variables are manipulated in the experimental group. The results obtained are then compared with those of the control group. In this study, not all variables and experimental conditions can be strictly controlled; therefore, a quasi-experimental 2 × 3 factorial design is employed. The independent variables are learning models and learning styles, while the dependent variables are critical thinking skills and self-efficacy. Prior to the intervention, all participants will complete a validated learning style inventory to identify their dominant learning preferences, which align with established frameworks such as visual, auditory, and kinesthetic modalities.

Research Sample

The study population consisted of 189 tenth-grade students at SMA Negeri 5 Ternate City, Indonesia. From this population, a random sample of 108 students was selected, ensuring that all members of the population had an equal chance of being selected as respondents. The selected sample comprised two experimental and two control classes. The experimental group consisted of 54 students, and the control group consisted of an equal number of 54 students.

Treatments

The experimental group will be involved in a chemistry curriculum delivered through PBL. In PBL, students work in small collaborative groups to learn the skills necessary for problem-solving. The learning model's syntax is based on Arends (2012), as explained in Table 1. The control group will receive direct learning instructions with a scientific approach and group learning. The control and experimental groups use the same chemical material. PBL education in this study is structured intensively over 8 weeks, with each meeting lasting 90 minutes or 2 hours. The ninth meeting serves as a post-test to assess critical thinking skills and student self-efficacy. The topics of chemistry learning for grade 10 semester given are: atomic structure and fundamental laws of chemistry. All groups, both experimental and control, will first be assessed for their learning styles. Treatment for each learning style characteristic is also provided to all groups, such as students with a visual learning style who prefer information presented in charts, diagrams, mind maps, graphs, and other symbolic forms rather than words. Students with an auditory learning style prefer listening to audio lessons. Students with a kinesthetic learning style tend to prefer practical learning experiences that incorporate simulations and involve a range of movements.

Table 1. Syntax of the problem-based learning model

Phase	Teacher Activity
Phase 1: Student orientation to the problem.	The teacher introduces the learning objectives and motivates students to actively solve the assigned problems.
Phase 2: Organizing students.	The teacher assists students in designing and organizing learning tasks related to the problem. At this stage, the teacher also forms study groups.
Phase 3: Guiding individual and group research.	Teachers facilitate students in collecting relevant information, conducting experiments, and finding solutions to problems they face.
Phase 4: Developing and presenting the work.	Teachers guide students to plan and compile learning products, such as reports, and share the results of their work with other group members.
Phase 5: Analyze and evaluate the problem-solving process.	The teacher accompanies students in reflecting on and evaluating the process and results of problem-solving that has been carried out.

Research Instruments

VAK Learning Styles Inventory

This study used the VAK Learning Style Inventory questionnaire. VAK stands for visual (V), auditory (A), and kinesthetic (K). Students completed the VAK Learning Style Inventory, as described by Sugianto (2021), which consists of 14 questions with three pre-validated answer choices. The student's answer, which corresponds to the most frequently chosen learning mode, is the dominant learning style. The VAK learning style instrument used is shown in Appendix 1.

Critical Thinking Skills Instrument

Critical thinking skills adapted from the synthesis of Ennis (2011), Facione (2015), and WGCTA frameworks, as modified by Sugrah et al. (2023), with indicators in Table 2. The critical thinking skills test consisted of 15 items, which five experts validated. The validation results were then used in Aiken's analysis to evaluate the test's validity. After expert validation, empirical validation was also conducted on 54 11th-grade high school students. The trial results were then analyzed using the Rasch Model to assess item suitability. The analysis results showed that 10 items met the validity criteria. The following analysis involved calculating reliability using Cronbach's alpha. The Rasch model input reliability was 0.71, indicating that the critical thinking skills test was reliable. The Critical Thinking Skills Instrument is presented in Appendix 2.

Table 2. Indicators of critical thinking skills

No	Aspect	Indicator	Definition
1.	Introduction of assumptions	Identifying assumptions Assessment of assumptions	Students' ability to identify, state, and explain the assumptions underlying a statement or argument.
2.	Providing a basic explanation	Focusing on the question Analyzing arguments	The student's ability to provide a simple scientific explanation of a concept, phenomenon, or relationship between variables using relevant basic principles.
3.	Interpretation	Categorizing Clarifying the meaning	Students' ability to interpret data, graphs, diagrams, and other information.
4.	Analysis	Testing ideas Identifying arguments Identifying reasons and questions	Students' ability to break down information or arguments into the main components of claims, evidence, reasons, and logical relationships.
5.	Evaluation	Assessing the credibility of the question Assessing the quality of arguments made with inductive or deductive reasoning.	Students' ability to assess the accuracy of concepts, the reliability of evidence, the validity of logic, and the strength of scientific arguments, and to assess whether conclusions are in accordance with the data or principles used.
6.	Summing up	Deducing and considering deductions Inducing and considering the results of induction Creating and assessing the values of the results of consideration.	Students' ability to draw conclusions based on analysis and evaluation of available chemical information or data.

Self-Efficacy Instrument

This self-efficacy questionnaire consists of 26 statements, each rated on a 4-point scale (1 = never, 4 = always). This self-efficacy questionnaire was adapted from the research of Fitriyana et al. (2018) and demonstrated a reliability coefficient of 0.72. Although the adopted self-efficacy instrument was valid and reliable, it was recalculated for its validity and reliability. The validity results, as tested using construct validity with students and then calculated using the SQUEST application, were 0.81, and the reliability was 0.75. The self-efficacy questionnaire consists of four aspects: effort and perseverance, task orientation, confidence, and performance. The self-efficacy instrument used is presented in Appendix 3. The self-efficacy indicators are presented in Table 3.

Table 3. Self-efficacy indicators

Indicators	Definition
Task Orientation	Accepting challenging assignments.
Effort and Perseverance	Increase effort when facing challenging tasks and persist when goals are not achieved

Confidence	Believe in success, control depression and anxiety when goals are not achieved, and believe that you can control your environment.
Performance	Able to do better than other students who have equal abilities

Data Analysis Techniques

The first data analysis used was descriptive, to determine the average, maximum, minimum, and standard deviation. Next, the normality assumption was tested using the Kolmogorov-Smirnov test on the data on critical thinking skills and self-efficacy in both the experimental and control classes, followed by a homogeneity test using Levene's Test. After the data were found to be normal and homogeneous, the analysis continued with a Two-Way Analysis of Variance (ANOVA) to test the effects of learning styles and learning models on critical thinking skills and self-efficacy, as well as the interaction between the two on these outcomes. The results of the two-way ANOVA test revealed a significant difference, followed by a Post Hoc test using the Tukey HSD method to identify which group pairs differed significantly. The significance level used in the analysis was 5% ($\alpha = 0.05$).

▪ RESULT AND DISSCUSSION

Descriptive Analysis Results

The results of the descriptive analysis of critical thinking skills are presented in Table 4 below.

Table 4. Results of descriptive analysis of critical thinking skills

Learning Style	Group	Mean	Std. Deviation	N
Visual	Experimental	78.59	4.171	29
	Control	72.37	5.746	27
	Total	75.59	5.855	56
Audio	Experimental	78.72	4.750	18
	Control	73.17	4.575	24
	Total	75.55	5.370	42
Kinestetik	Experimental	86.29	5.964	7
	Control	75.67	7.506	3
	Total	83.10	7.909	10

The results of the analysis show that the number of students with visual learning styles is 56, those with audio learning styles is 42, and those with kinesthetic learning styles is 10. The average critical thinking skills for visual, audio, and kinesthetic learning styles are 75.59, 75.55, and 83.10, respectively. The average critical thinking skills in the experimental class are always higher than those in the control class. The results of the self-efficacy analysis indicate that the visual learning style has a score of 78.63, the audio learning style has a score of 77.31, and the kinesthetic learning style has a score of 84.20. The average self-efficacy in the experimental class is always higher than in the control class.

The Influence of Learning Styles and Learning Models on Students' Critical Thinking Skills in Chemistry

The results of the two-way ANOVA analysis are presented in Table 5 below.

Table 5. Results of the analysis of the influence of learning styles and learning models on critical thinking skills

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	1608.843[a]	5	321.769	12.940	.000	.388
Intercept	334976.204	1	334976.204	13471.050	.000	.992
Learning Styles	222.342	2	111.171	4.471	.014	.081
Group	777.340	1	777.340	31.261	.000	.235
Learning Styles* Group	44.971	2	22.486	.904	.408	.017
Error	2536.370	102	24.866			
Total	632369.000	108				
Corrected Total	4145.213	107				

The results of learning styles on critical thinking skills are significant. Value of 0.014 < 0.05, indicating an influence of student learning styles on critical thinking skills. The results, with a significance value of 0.000 < 0.05, indicate that learning models have a significant impact on critical thinking skills. The influence of learning styles and learning models has a significance value of 0.408, which is greater than 0.05, indicating that there is no significant influence of these factors on critical thinking skills.

Based on the data analysis of the influence of learning styles on critical thinking skills, a p-value of 0.014 < 0.05 indicates that learning styles have a significant effect on critical thinking skills. The results of this study also show that the kinesthetic learning style outperforms the audio and visual learning styles in terms of critical thinking skills. Several research results support this, including those showing that kinesthetic students tend to be more actively involved in the learning process when it is grounded in real experiences and involves physical movement (Azlan et al., 2025). Additionally, other research indicates that students with high learning outcomes are more likely to employ the kinesthetic learning style than other learning styles (Khanal et al., 2019). Furthermore, other research results found a significant correlation between critical thinking and the kinesthetic learning style (Nosratinia & Soleimannejad, 2016). These research results underscore the importance of tailoring learning strategies to accommodate students' diverse learning styles, thereby optimizing the development of critical thinking skills.

Learning styles play a significant role in developing critical thinking skills (Dilekli, 2017). Learning styles can be stable and evolve depending on students' learning habits (Wong & Nunan, 2011). Educators need to consider each student's learning style, material characteristics, classroom environment, methods, and strategies, as learning styles can change over time and adapt to individual needs (Shamsuddin & Kaur, 2020). This approach will be more effective because students can adapt to the learning environment themselves, thereby enhancing their learning experience, rather than expecting them to adapt to the environment (Uğur et al., 2011). Therefore, considering students' learning styles in the learning process not only improves the desired learning outcomes but also supports the development of critical thinking skills. When students can learn in a way that suits their individual characteristics or learning styles, they will quickly understand and evaluate the information they receive. In this context, critical thinking involves introducing assumptions, providing basic explanations, interpreting, analyzing, evaluating, and drawing logical conclusions. This aspect will be easily achieved by students when they feel comfortable and involved in a learning process tailored to their learning style.

The analysis of learning models on critical thinking skills is a significant influence. Specifically, the PBL learning model emphasizes problem-solving related to everyday life and group learning. Through these activities, students can apply their knowledge in real-world situations, thereby developing critical thinking skills. This process aligns with the findings of Liu & Pásztor (2022), who demonstrated that PBL interventions can enhance students' critical thinking skills. Furthermore, supporting evidence from other research indicates that PBL is a primary approach in teaching that can develop various abilities, including critical thinking (Razak et al., 2022). Notably, critical thinking is a crucial personal trait that enables individuals to make informed decisions through comprehensive analysis and assessment (Richards, 2025). In line with these insights, this study found that PBL interventions engaged students in problem-solving, group discussions, and investigations, providing ample opportunities for exchanging ideas and intellectual engagement, thereby encouraging their critical thinking (Aslan & Duruhan, 2021).

The Influence of Learning Styles and Learning Models on Student Self-Efficacy in Chemistry Learning

The results of the analysis of learning styles and learning models on student self-efficacy are presented in the following Table 6.

Table 6. Analysis of learning styles and learning models on self-efficacy

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	988.250^a	5	197.650	8.831	.000	.302
Intercept	351217.278	1	351217.278	15692.151	.000	.994
Learning Styles	121.062	2	60.531	2.704	.072	.050
Learning model	569.983	1	569.983	25.466	.000	.200
Learning Styles* Learning model	171.345	2	85.673	3.828	.025	.070
Error	2282.935	102	22.382			
Total	670994.000	108				
Corrected Total	3271.185	107				

The results of the learning style test on self-efficacy showed a p-value of 0.072 ($p > 0.05$), indicating that student learning styles did not influence self-efficacy. This result, with a significance value of $0.000 < 0.05$, indicates that the learning model has a significant influence on student self-efficacy. The influence of learning styles and learning models on self-efficacy has a significance value of 0.025, which is smaller than 0.05, indicating a significant effect.

The analysis of the influence of learning styles on self-efficacy reveals that they do not have a significant impact. This study reveals that students' learning styles do not directly impact their beliefs in their own ability to overcome challenges. However, these learning styles do influence their capacity to absorb information. Self-efficacy plays a crucial role in enhancing motivation and persistence in the learning process. Self-efficacy refers to students' beliefs in their ability to succeed in tasks and face specific challenges. The study's findings suggest that although learning styles can influence how students engage with course materials, other elements more closely linked to their educational experiences have a greater impact on students' self-efficacy. Acquired knowledge must be incorporated into a self-regulation cycle, where a combination of strategies, abilities, and information is applied to worthwhile and challenging activities to foster self-efficacy (Graham, 2022). Additionally, direct experience (mastery experiences), peer or teacher feedback, and societal pressures are among the elements that may affect students' self-efficacy (Pajares, 2003). Although students' choices for learning modalities can be influenced by learning styles such as visual, auditory, or kinesthetic, other psychological aspects related to their experiences completing academic assignments are more significant in forming their self-efficacy.

Research by Chou & Wang (2000) reveals that students' self-efficacy is more influenced by successful learning experiences and positive feedback delivered through more individualized and reflective instruction than by learning style alone. Regardless of their preferred learning method, students who had positive learning experiences, such as completing challenging assignments, had higher self-efficacy. Other research findings indicate that Tuan et al. (2005) demonstrated that social and motivational factors—such as support from peers and teachers, as well as students' intrinsic motivation—have a stronger influence on self-efficacy than learning styles. While learning styles contribute to how students learn, their impact on self-confidence in facing academic challenges is generally more limited.

Furthermore, the research indicates that PBL has a positive impact on student self-efficacy. These results align with Syarafina et al. (2018), who found that PBL supports students' knowledge and self-efficacy. Later studies also report that student self-efficacy rises with the use of PBL (Smith & Hung, 2017). PBL interventions provide students with opportunities to collaborate in groups and build confidence when facing challenges, thereby strengthening their self-efficacy. PBL presents problems at the start of lessons, often relating to everyday life. This enables students to engage with and analyze solutions as they learn and develop their skills. Using real-life problems not only builds problem-solving skills but also self-efficacy (Liu & Pásztor, 2022).

The results of this study also indicate that learning styles and models affect students' self-efficacy. This influence is important because self-efficacy, a key motivational factor, significantly shapes students' perceptions of their abilities and the learning approaches they subsequently adopt (Laitinen et al., 2024). Specifically, an individual's belief in their capacity to organize and execute actions to achieve desired outcomes is key to their academic persistence and success (Ojeh et al., 2023). High self-efficacy can significantly enhance students' self-regulated learning abilities and overall academic performance by fostering more sophisticated behavioral characteristics during performance and self-reflection, as well as the use of advanced cognitive and metacognitive strategies (Chen et al., 2024). Conversely, lower self-efficacy tends to correlate with shallow learning methods, whereas higher self-efficacy is often associated with deeper, more strategic learning approaches (Laitinen et al., 2024).

According to self-efficacy theory, students' persistence, effort, and self-regulation are influenced by their sense of self-efficacy, which, in turn, leads to more favorable learning outcomes. Empirical studies provide more evidence for this. Elements That Affect Self-Efficacy: According to earlier research, self-efficacy is a fundamental aspect of self-regulation, and self-regulated learning is intimately linked to the application of strategies, causal attribution, and metacognition (Graham, 2022). Bandura's (2009) social-cognitive theory posits that self-efficacy, an individual's belief in their ability to carry out the actions necessary to achieve a specific outcome, serves as an important mediator between the learning environment and cognitive outcomes. In the context of this study, implementing PBL provides a learning environment rich in social interaction and authentic problem-solving, where students actively engage in identifying issues, discussing them in groups, and evaluating the resulting solutions. This process allows for successful experiences and social learning, ultimately strengthening self-efficacy and enhancing critical thinking skills.

The Interaction between Learning Styles and Learning Models

The interaction between learning styles and learning models on critical thinking skills is illustrated in Figure 1 below.

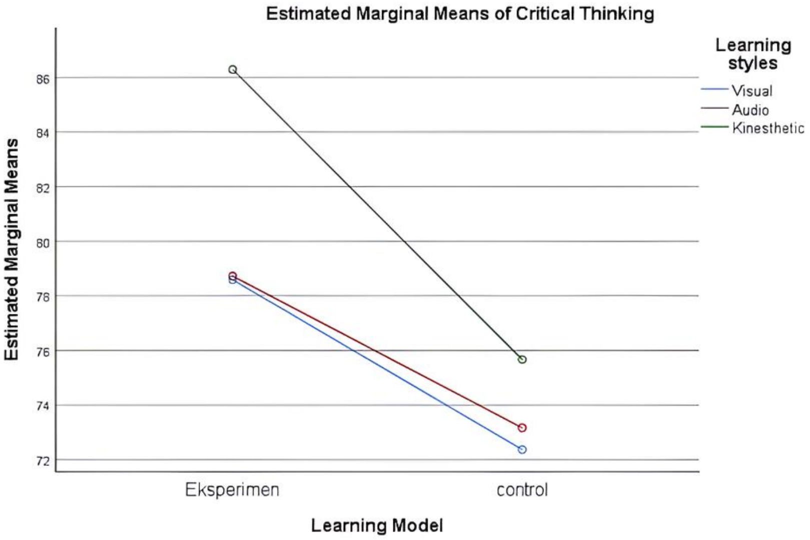

Figure 1. Interaction between learning styles and learning models on critical thinking skills

Figure 1 above shows no interaction between the learning model and the learning style on critical thinking skills. Because learning styles have different impacts on critical thinking skills, a post hoc test was conducted to assess the significance of these differences. The results of the post-hoc test are presented in Table 7 below.

Table 7. Poshoc test of learning styles on critical thinking skills

	Learning Styles	Learning Styles	Mean Difference	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Tukey	Visual	Audio	.04	1.018	.999	-2.38	2.46

HSD		kinestetic	-7.51*	1.712	.000	-11.58	-3.44
	Audio	Visual	-.04	1.018	.999	-2.46	2.38
		kinestetic	-7.55*	1.755	.000	-11.73	-3.38
	kinestetic	Visual	7.51*	1.712	.000	3.44	11.58
		Audio	7.55*	1.755	.000	3.38	11.73

The Tukey HSD test revealed no significant difference between visual and auditory learning styles, whereas significant differences were observed among the others. The interaction between learning styles and learning models on self-efficacy is presented in Figure 2.

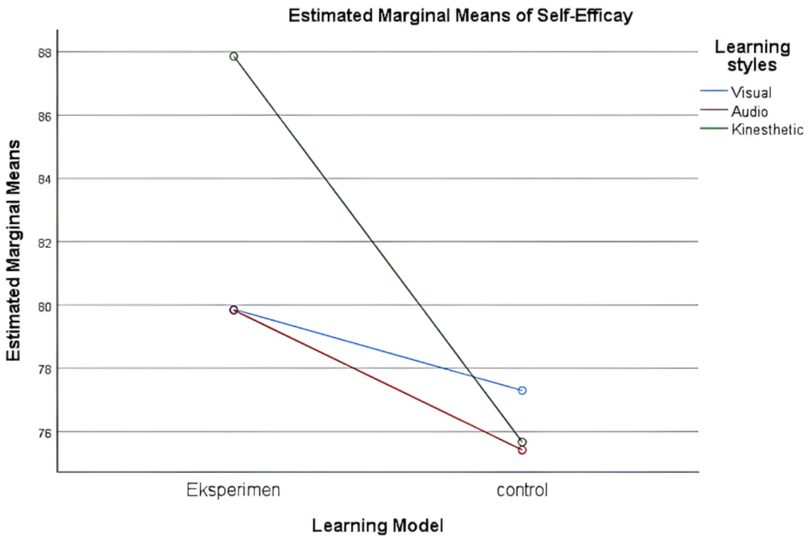

Figure 2. Interaction between learning styles and learning models on self-efficacy

The results of the interaction between learning models and learning styles showed that kinesthetic learning styles in the experimental class were higher than visual and auditory learning styles. In PBL, kinesthetic students benefited more from engaging in hands-on practice, experiments, and problem-solving activities that provided real-life experiences of success. Visual students experienced moderate benefits from using images, models, and visual reports during the PBL process. However, for auditory learners, PBL activities that emphasized group work and practice often lacked the verbal feedback they needed, leading to suboptimal self-confidence. These findings align with the results of a meta-analysis (Wijnia et al., 2024), which concluded that the impact of PBL on student motivation and self-confidence is highly dependent on the quality of support (scaffolding) and group dynamics. Research by Ghani et al. (2021) also demonstrated that PBL effectiveness increases when interactions and feedback are tailored to students' learning characteristics. Therefore, implementing adaptive PBL should balance visual, verbal, and practical aspects to ensure all students gain learning experiences that strengthen their self-efficacy.

This study also examined the interaction between learning models and styles, and found that although both had a significant impact on critical thinking abilities, there was no significant interaction between them. This result suggests that although pedagogical approaches and individual learning preferences both independently support cognitive development, their combined impact on critical thinking may not exhibit a synergistic relationship, indicating the need for further research on additional contextual factors (Fuad, 2020). The relative significance of each component in promoting the development of critical thinking, as well as their interactions, might be investigated in further detail (Yu & Zin, 2023). Although this result supports earlier studies showing the separate impacts of instructional approaches and learning styles, it also creates new opportunities to investigate mediating factors that may shape their interactions (Verawati et al., 2020).

Statistical results indicate an interaction between learning styles and learning models on students' self-efficacy, particularly for visual and kinesthetic learning styles. While learning styles influence how students interact with learning materials, learning models also influence students' self-efficacy (Shin, 2018). Flexible, student-centered learning models, such as PBL, adapt to each individual's learning style and encourage greater confidence in addressing learning challenges (Farhang et al., 2020). For example, students with kinesthetic learning styles who engage in practical PBL activities are more likely to gain successful experiences, thus strengthening their self-efficacy. Furthermore, the interaction between learning styles and learning models suggests that a more tailored approach to students' needs can strengthen their motivation and self-efficacy. Visual or auditory learners, for example, may benefit from learning models that integrate visualizations or audio-based discussions, allowing students to feel more engaged and better understand the material. Therefore, although learning styles and learning models can have separate effects, the synergy between the two has a greater impact on increasing students' self-efficacy, because students feel more valued and supported in ways that suit their learning style.

This research can serve as a starting point for future research and development in chemistry learning, focusing on developing a more adaptive PBL model tailored to students' diverse learning styles, including visual, auditory, and kinesthetic. This strategy is expected to develop students' activeness, critical thinking skills, and self-efficacy. Furthermore, learning strategies should incorporate strategies that strengthen self-efficacy, such as gradual experiences, constructive feedback, mentoring, and self-reflection. The use of technology and interactive media, such as chemistry simulations, virtual laboratories, and animations, can also support the understanding of abstract concepts and encourage active student participation. Collaboration and group discussions in PBL should be strengthened to develop analytical skills, scientific communication, and critical thinking. Further research is also recommended to investigate the impact of social and emotional factors, including teacher and peer support, as well as intrinsic motivation, on the development of critical thinking and self-efficacy. Finally, a longitudinal research design can help understand changes in learning styles, the effectiveness of PBL, and the development of students' critical thinking skills and self-efficacy over a longer period.

This study is limited by the imbalance in sample size across learning style groups. This distribution reflects the actual results of the Student Learning Style Inventory. However, the small kinesthetic group may affect the homogeneity of variance and reduce statistical power. Results for this group should be interpreted with caution. The homogeneity test met the assumptions, but this imbalance remains a limitation of the study. Future research should use a larger sample to balance the groups and continue to consider the homogeneity test for learning style.

▪ CONCLUSION

The results of this study indicate that learning models and learning styles have different effects on students' critical thinking skills and self-efficacy in chemistry learning. The Problem-Based Learning (PBL) model was shown to significantly improve critical thinking skills and self-efficacy, as students were able to connect concepts to everyday life contexts through real-life problem-solving and collaborative work. Learning styles also significantly influenced critical thinking skills, with students with kinesthetic learning styles demonstrating higher critical thinking skills than those with visual or auditory learning styles. However, learning styles did not significantly influence self-efficacy, suggesting that student confidence is more strongly influenced by successful experiences, positive feedback, and social support received during the learning process. Theoretically, these findings support Bandura's social cognitive theory and the constructivist perspective, which emphasizes that active, collaborative, and authentic experience-based learning can strengthen cognitive engagement and build student self-efficacy.

This study also recognizes the fundamental limitations of using the VAK learning styles framework. Although this framework is widely used in educational practice, empirical evidence supporting its validity as a basis for understanding individual differences in learning remains weak, so interpreting the results requires caution. The findings of this study are not intended to assert that adapting learning models to specific learning styles will directly improve learning outcomes; instead, they aim to demonstrate that pedagogical flexibility in adaptive PBL models can strengthen students' motivation and self-efficacy. In practice, these results imply the importance of developing PBL models that are more adaptive to student characteristics and of strengthening self-efficacy-enhancing strategies through incremental experiences, constructive feedback, self-reflection, and social collaboration. Limitations of this study include unequal sample sizes across learning style groups and the failure to control for confounding variables, such as initial academic ability, motivation, and teacher instructional variation. Further research is recommended using mixed-method or longitudinal designs to more comprehensively explore the development of learning styles, the effectiveness of PBL models, and the social-emotional factors that mediate the relationship between learning models, learning styles, and student learning outcomes.

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Questionnaire Sheet
Determining Student Learning Style Types

Appendix 1

1. I really like…….
   a. Taking notes
   b. Telling stories
   c. Tracing
2. I like reading with…….
   a. Fast
   b. Loudly
   c. Finger as a pointer
3. I like learning best with………
   a. Reading
   b. Listening
   c. Moving
4. I easily remember what……….
   a. I see
   b. I hear
   c. I write
5. When I take notes, I…
   a. Take lots of notes with pictures
   b. Take a few notes because I prefer listening
   c. Take lots of notes, but no pictures
6. I answer questions with…
   a. Yes or no
   b. Long-winded (like to tell stories)
   c. Followed by body movements
7. When I study…
   a. Not easily distracted by noise
   b. Easily distracted by noise
   c. Cannot sit still for long periods
8. I remember by…
   a. Imagining
   b. Speaking
   c. While walking and looking
9. I prefer to speak…
   a. Looking at faces directly
   b. Over the phone
   c. Paying attention to body movements
10. When I speak…

   a. Fast
   b. Intonation/rhythm
   c. Slow
11. My usual learning method is…
    a. Following picture instructions
    b. While talking
    c. While talking while writing
12. I often spend my free time by…
    a. Watching
    b. Listening to music
    c. Playing games
13. I understand lessons more easily by…
    a. Looking at demonstrations
    b. Discussing
    c. Practicing
14. I prefer….
    a. Pictures
    b. Music
    c. Games

Appendix 2

Instrument Critical Thinking Skills

<table>
<tr><th>Aspect</th><th>Question</th></tr>
<tr><td>Task Orientation</td><td>1. A student concludes that two different samples of a substance are still composed of the same type of elementary particles. Explain this statement in relation to Dalton's atomic theory.</td></tr>
<tr><td></td><td>2. Water (H_2O) is constantly formed from hydrogen and oxygen in a constant mass ratio of 1:8, even if they come from different sources. Explain why the mass ratio of elements in a compound always remains constant according to the fundamental laws of chemistry!</td></tr>
<tr><td>Providing a basic explanation</td><td>1. Explain the role of each subatomic particle in determining the properties of an atom!
2. A solution of $AgNO_3$ is mixed with a solution of NaCl, forming a white precipitate of AgCl.
a. Write the complete reaction!
b. What characteristics indicate that this process is a chemical reaction? Explain</td></tr>
<tr><td>Interpretation</td><td>1. The following table shows the number of subatomic particles of two different atoms:
<table>
<tr><th>Atom</th><th>Proton</th><th>Neutron</th><th>Electron</th></tr>
<tr><td>X</td><td>11</td><td>12</td><td>10</td></tr>
<tr><td>Y</td><td>11</td><td>12</td><td>11</td></tr>
</table>
Explain the differences in the properties of the two atoms and what causes these differences!</td></tr>
</table>

<table>
<tr><td></td><td>2. In two different experiments, water was obtained as follows:
<table><tr><th>Experiment</th><th>Mass $H_{2(g)}$</th><th>Mass $O_{2(g)}$</th><th>Mass $H_2O_{(g)}$</th></tr><tr><td>1</td><td>2</td><td>16</td><td>18</td></tr><tr><td>2</td><td>4</td><td>32</td><td>36</td></tr></table>
Explain the data based on Proust's or Dalton's Law!</td></tr>
<tr><td>Analysis</td><td>1. An atom with a charge of -2 has an atomic number of 16 and a mass number of 34.
a. Analyze the change in the number of subatomic particles that causes the atom to become charged.
b. Determine the number of protons, electrons, and neutrons in the ion.
2. Given 2.5 grams of magnesium, react completely to form magnesium oxide. If the mole mass of Mg = 24 g/mol and MgO = 40 g/mol:
a. Calculate the number of moles of Mg that reacted.
b. What is the mass of moles of O that bind to 2.5 g of Mg in the reaction?
c. Analyze whether your results conform to the law of definite proportions (Proust's Law).</td></tr>
<tr><td>Evaluation</td><td>A sample of gaseous element X has a mass of 6.4 grams. It is known that element X has an electron configuration of 2, 8, 2.
a. Identify element X based on its electron configuration.
b. Calculate the number of moles of element X in the sample.
c. Explain how the electron configuration of the element relates to its tendency to form ions in chemical reactions.</td></tr>
<tr><td>Summing up</td><td>A sample of element X has a mass of 12 grams. The average relative atomic mass (Ar) of element X based on its isotopic abundance is 24. Element X is in group 2 and period 3 of the periodic table.
a. Calculate the number of moles of element X in the sample.
b. Based on its periodic position, explain the trend of the atomic radius of element X compared to elements in the same period and group.
c. Based on the given mole mass data and periodic properties, conclude the reactivity characteristics of element X in forming ionic compounds.</td></tr>
</table>

Appendix 3

Self-Efficacy Instrument

Aspect	Question
Task Orientation	1. I enjoy challenging assignments because they motivate me to learn chemistry. 2. For me, challenging assignments are a threat to be avoided. 3. I am interested in completing challenging assignments using various methods. 4. I am reluctant to undertake challenging assignments. 5. I feel capable of managing my time well to complete each chemistry assignment given.

	6. I am confident that I can understand chemistry well if I diligently complete the assignments.
Effort and Perseverance	1. I can work hard on challenging assignments. 2. I give up when faced with difficult material. 3. I keep trying to complete independent assignments given by my teacher until I am finished. 4. I am not enthusiastic about completing independent assignments given by my teacher. 5. I will keep trying until I have completed all the assignments I have not mastered. 6. I will submit assignments on material I have not mastered to the best of my ability. 7. I spend more time studying the material.
Confidence	1. I am confident in controlling my anxiety when facing difficulties on daily tests. 2. I feel disappointed when I fail a daily test. 3. I can regain my confidence after failing a daily test. 4. I struggle to rebuild my confidence in chemistry after failing a test. 5. I am not confident in my ability to learn the material well. 6. I can follow the material well, even though the facilities are not supportive.
Performance	1. I am confident in doing well on chemistry assignments because I have completed previous assignments. 2. My previous successful experiences make me confident in tackling more difficult chemistry material. 3. I feel capable of solving chemistry problems because I have often succeeded in previous practice sessions. 4. My success in previous chemistry lessons makes me confident that I can achieve even better learning outcomes. 5. I feel more confident doing chemistry assignments when I remember my success on previous assignments. 6. My success in understanding previous chemistry concepts makes me confident in understanding new concepts. 7. I am confident that I can achieve good grades in chemistry because my learning experience so far has shown satisfactory results.