

Metacognitive Problem-Based Learning Model as an Alternative to Improve Student Learning Outcomes in the Stoichiometry Solution Concept

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Article Info	Abstract
Article history: Received: May 5, 2025 Accepted: July 18, 2025 Published: October 14, 2025 Keywords: Learning outcome Metacognitive strategy Problem-Based learning Stoichiometric solution concept This article is licensed under a Creative Commons Attribution-ShareAlike 4.0 International License. © 2025 Journal of Mathematics, Science, and Computer Education	A study has been conducted on applying the metacognitive-problem-based learning (M-PBL) model to stoichiometric solutions. The research aims to identify differences between models in learning grade-class outcomes. This quasi-experimental study involved students at SMAN 2 Banjarmasin. The research used a quasi-experimental design with a pretest-posttest nonequivalent control group. The sample from all populations (total sampling). Test instruments to measure students' learning outcomes. Questionnaires for measuring students' metacognition. The observer measures students' activity and qualitative explanations from the results of student and teacher interviews. The result shows there is a significant difference in learning outcomes by ANOVA test among M-PBL, M-DI, and DI classes; (2) the best student learning achievement is in the M-PBL group, which is shown by the Duncan test at α 0.05; and (3) the percentages of student learning process in the M-PBL group, M-DI group, and DI group were 77.82, 73.44, and 55.66%, respectively. The M-PBL model can improve student learning processes and outcomes, so it should be implemented in schools.
To cite this article: Syahmani, S., Apriyani, N., & Khodizah, A. T. (2025). Metacognitive problem-based learning model as an alternative to improve student learning outcomes in the stoichiometry solution concept. <i>Journal of Mathematics, Science, and Computer Education</i>, 5(2), 115-129.	

INTRODUCTION

Meaningful learning enhances knowledge retention and facilitates subsequent learning. Therefore, students need to be familiar with the strategies used in the learning process. Learning strategies can be categorized into two: cognitive strategies that help achieve goals in solving conceptual and contextual problems, and metacognitive strategies that monitor progress achieved (Widyantari et al., 2019). In metacognitive strategies, students are assisted to be aware of learning goals, abilities, planning, monitoring, and self-assessment (Nilson & Zimmerman, 2023; Belenkova, 2021). The application of learning models and strategies promotes students' activeness, awareness, and thinking processes, which become meaningful for students. Learning strategies also affect learning outcomes. The utilization of metacognitive strategies improves scientific problem-solving abilities (Avargil et al., 2018; Iskandar, 2014).

Stoichiometry is a branch of chemistry focusing on the quantitative relationships between reactants and products in chemical reactions (Niaz & Montes, 2012). By understanding stoichiometry, we can perform accurate calculations in various chemical applications, including synthesis, analysis, and industry. In the field, we observe that students who learn chemistry

experience difficulties in solving stoichiometry problems. Evidence in chemistry learning includes (1) weak conceptual understanding due to abstract chemical concepts, learning difficulties, and misconceptions in chemistry (Tümay, 2016; Quílez, 2019; Kapici, 2023; Syahmani et al., 2023), (2) weak conceptual and algorithmic stoichiometry (Stott, 2020), and (3) low students' learning outcomes because they do not involve conceptual understanding and metacognitive skills (Kousa et al., 2018; Syahmani et al., 2020). Most reported metacognition-related studies in chemistry education show that metacognitive strategies are often implicitly taught through learner engagement in activities to enhance these skills (Alkan & Erdem, 2014; Dori & Avargil, 2015; Casselman & Atwood, 2017). The solution requires learning innovation by design and the development of teaching materials to equip students with metacognitive skills and an understanding of problem-solving concepts.

Metacognition is commonly described as "thinking about one's thinking" (Driessen, 2014; Syahmani et al., 2023). In the learning context, students understand how to learn, their learning abilities and modalities, and the most effective learning strategies for achieving success. In the realm of metacognition, a common differentiation is established between knowledge of cognition, referred to as metacognitive knowledge, and the regulation of cognition, known as metacognitive regulation (Abdellah, 2015; Schraw et al., 2006; Schraw & Dennison, 1994). Metacognitive knowledge consists of (1) declarative knowledge, (2) procedural knowledge, and (3) conditional knowledge, while metacognitive regulation consists of abilities (1) planning, (2) information management strategies, (3) comprehension monitoring, (4) debugging strategies, and (5) evaluation (Kallio et al., 2018; Rompayom et al., 2010; Schraw & Dennison, 1994)—The definitions of metacognitive knowledge and regulation in Figure 1.

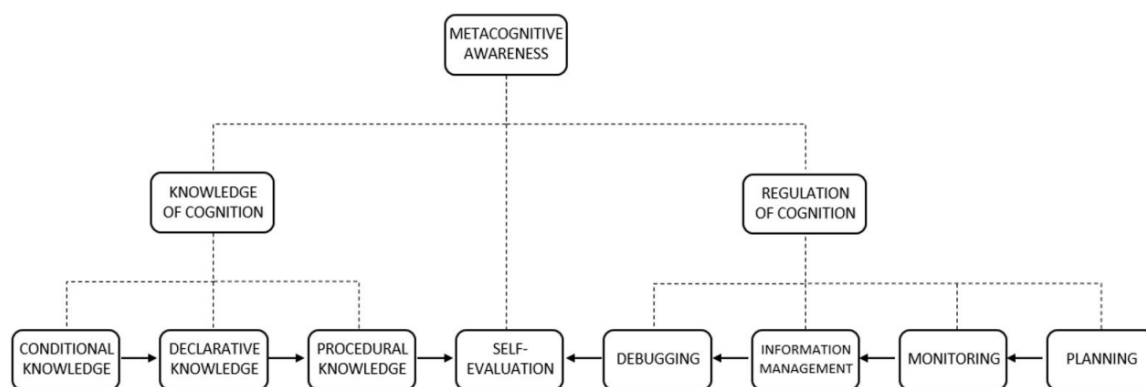


Figure 1 Classification of metacognitive awareness components

Descriptions:

Knowledge is declarative: knowledge about the information required for tasks.

Knowledge is procedural: understanding oneself in relation to a task or how one views one's ability to do something.

Knowledge conditional: Knowledge of when and why to use specific strategies to solve problems.

Planning: Ability to plan learning activities.

Information management strategies: Strategic ability to manage information

Comprehension monitoring: Ability to monitor the learning process

Debugging strategies: Strategies for correcting wrong actions.

Evaluation: Ability to evaluate the effectiveness of learning strategies.

Teachers can assist students to achieve success in learning using metacognitive strategies. Pulmones (2008) and Syahmani et al. (2022) developed three stages of the metacognitive strategy, each with a student learning activity, as shown in Table 1.

Table 1 Student learning activities in each stage of the metacognitive strategy

Stages	Learning activities
Level of awareness (consciousness of learning)	• Think and write about what you know and do not know. Set the learning goals process. • Consider the learning resources that can be accessed and the learning motivation. • Determine the level of learning difficulty.
Level regulation (planning and monitoring)	• Estimate the time required to complete the task. • Plan study time in the form of a schedule to determine the priority scale in learning. • Organizing lesson material and taking appropriate steps to learn • Keep trying to understand; it requires repetition, using graphic organizers, reviewing solutions and tests, solving more problems, and checking progress against goals.
Level reflection (evaluation)	• Reflect by checking the written goals that can be achieved. • Reflect on learning strategies by identifying those that work and those that do not. • Assessing how study strategies can be applied in other learning contexts. • Maintain high concentration and motivation in learning.

Research underscores the complexities inherent in teaching stoichiometric calculations, which are often perceived as abstract. Research highlights the complexities of teaching stoichiometric calculations, which are considered an abstract subject (Kimberlin & Yeziarski, 2016). The concept of moles in stoichiometry poses a significant challenge for students, leading to ineffective problem-solving. Students frequently resort to memorizing procedures rather than comprehending the underlying chemical interactions, thereby impeding their ability to categorize and address problems with the proficiency of experts. This study is crucial because of the low levels of conceptual understanding, metacognition, and chemical problem-solving observed among Indonesian high school students (Haryani et al., 2018; Anazifa & Djukri, 2017; Syahmani & Borneo, 2017), particularly in stoichiometric solutions.

A promising pedagogical approach that can enhance student engagement and learning outcomes is the problem-based learning (PBL) model (Mandina & Ochonogor, 2018; Qomariyah, 2019). Problem-Based Learning (PBL) seeks to enhance students' competence, motivation, and engagement while fostering a deeper understanding of how concepts apply to real-world scenarios, as key outcomes for learners (Alves et al., 2016). The PBL model's structure includes (1) orienting students to the problem, (2) organizing student learning, (3) guiding individual and group investigations, (4) developing and presenting work results, and (5) analyzing and evaluating the problem-solving process (Arends, 2012; Saadah & Irvan, 2019). This instructional model actively involves students, rendering learning both meaningful and comprehensible. By addressing real-world problems, PBL encourages metacognitive thinking and enables students to engage in inquiry, critical, and creative thinking (Marthaliakirana et al., 2022; Yazar Soyadi, 2015). This model also helps teachers design engaging metacognition-oriented lessons to improve students' interest and achievement (Wilder, 2015). Table 2 shows a relationship between the level of PBL implementation and metacognitive strategies, indicating that both can be combined in learning.

Table 2 M-PBL Model Syntax

The syntax of PBL	Metacognitive Level	Metacognitive Aspects
Orient students to the problem	Awareness (conscious learning process)	Study. Declarative knowledge
Organizing student learning	Planning	Learn planning skills
Guiding individual and group investigations	Monitoring	Declarative, procedural, conditional, and ability knowledge monitoring
Develop and present work results	Monitoring	Declarative, procedural, conditional, and ability knowledge monitoring

The syntax of PBL	Metacognitive Level	Metacognitive Aspects
Analyze and evaluate the problem-solving process	Reflection	Evaluation skills

Examining PBL through the lens of metacognition, which regulates and controls cognitive processes, is vital for effective scientific processes and learning outcomes (cognitive abilities) (Alrahlah, 2016; Gulacar et al., 2022; Khery & Ibnu, 2013). PBL enhances metacognition, helping students identify knowledge gaps and improve problem-solving skills (Aliyu et al., 2016; Dye & Stanton, 2017; Sutarto et al., 2022), thereby fostering a deeper understanding of chemistry and the development of autonomous skills, particularly in solution stoichiometry.

The integration of the metacognitive strategies-PBL model (M-PBL) in real-world contexts is anticipated to enhance students' learning outcomes. This study aimed to examine the differences in student learning outcomes among the M-PBL, Metacognitive Direct Instruction (M-DI), and Direct Instruction (DI) model interventions in the context of solution stoichiometry. Learning strategies are deliberate plans students formulate to achieve their educational objectives. Within the PBL framework, students are presented with problems to solve, thereby allowing them to apply metacognitive strategies that facilitate problem-solving.

METHODS

The quasi-experiment method was used in this study (Creswell, 2015; Fraenkel et al., 2023), which involves three groups: one control class and two experimental classes. The research design used is a pre-test post-test nonequivalent control group design, namely, research that uses initial tests (pre-test) and final tests (post-test). Subsequently, the condition of the dependent variable in the experimental group was compared with that in the control group after treatment. The research design is presented in Table 3.

Table 3 Research design: pre-test, post-test, nonequivalent control group design

Class	Pre-test	Treatment	Post-test
E _A	O ₁	X ₁	O ₂
E _B	O ₃	X ₂	O ₄
C	O ₅	X ₃	O ₆

Information:

E_A = Experimental class A (M-PBL)
E_B = Experimental class B (M-DI)
C = Control class (DI)
O₁, O₃, O₅ = Pre-test

O₂, O₄, O₆ = Post-test
X₁ = Learning with M-PBL Model
X₂ = Learning with M-DI Model
X₃ = Learning with DI Model

The research population was students of class XI Science, Senior High School 2 Banjarmasin, which consisted of five classes. Sample determination was carried out by *cluster random sampling*, namely, random sampling of classes. The research samples were class XI IPA 3 students as experimental class A, class XI IPA 4 students as experimental class B, and class XI IPA 5 as the control class, each consisting of 33 students.

The research involved two variables: (1) learning strategies and models, namely M-PBL in experimental class A, M-DI in experimental class B, and DI only in the control class, as the independent variables, and (2) student learning outcomes obtained through written tests and measured based on the scores obtained as the dependent variable.

To evaluate this prediction model, the following hypotheses were examined:

H1: Students' learning outcomes differ significantly among M-PBL, M-DI, and DI models in the solution stoichiometry topic.

H₀: No learning outcomes differ significantly among M-PBL, M-DI, and DI models in the solution stoichiometry topic.

Cognitive learning outcomes were assessed using instruments, while student metacognition was measured through metacognition questionnaires, observation of the learning process/working on worksheets, and interviews (Syahmani et al., 2023). Data collection was carried out in two stages: (1) the preparation stage, including the determination of the experimental and control classes as samples, the preparation of instruments, and the preparation of the learning implementation plan, and (2) the implementation stage, including the pre-test, the learning activities, the post-test, the observation of students' metacognitive activities and strategies with a questionnaire adapted from the Metacognitive Awareness Inventory (MAI) instrument (Vesga-Bravo, et al, 2024; Kallio et al., 2018; Schraw & Dennison, 1994), and data on student cognitive learning outcomes. The data analysis was carried out inferentially, including homogeneity and normality tests, a one-way ANOVA, and post hoc analysis with Duncan's test. In addition, a descriptive analysis was performed on the learning outcomes data, the student learning processes, and the interviews.

RESULTS AND DISCUSSION

The ANOVA Analysis

The acceptance or rejection of the research hypothesis was determined using variance analysis techniques. The hypothesis in this research is H_0 : there is no difference in learning outcomes between groups of students who study using only the M-PBL, M-DI, and DI models. Hypothesis testing using analysis of variance (ANOVA) was carried out under the assumption that the data are normally distributed and that the variances are homogeneous. Based on homogeneity testing of the Bartlett test and normality testing of the Lilliefors test, $F_{\text{count}} < F_{\text{table}}$ indicates that the data variance is homogeneous, and $L_0 < L$ shows the data in the three classes are normally distributed—the results of the ANOVA test in Table 4.

Table 4 Complete One-Way ANOVA Results for Significant Factors

Source	SS	df	Mean ²	F	$F_{\text{table}} (0,05)$ (2,100)		Conclusion
Between Groups	64.26	2	32.13	9.13	3.09	$F_{\text{count}} > F_{\text{table}}$ H_0 is rejected	There is a significant difference
Within Groups	337.76	96	3.52				
Total	402.02	98					

The one-way ANOVA analysis shows that H_0 is rejected. It indicates that students' learning outcomes differ significantly among M-PBL, M-DI, and DI models in the solution stoichiometry topic. To identify the most effective treatment with the best results, further post hoc analysis was performed. From the data, the Coefficient of Variation (CV) value of 12% was obtained in homogeneous conditions, so the most appropriate post-hoc analysis is the Duncan test in Table 5. The Duncan test was performed using SPSS for Windows, Version 17.0. Table 5 shows that the control class and experimental class B are in the same subset, while the experimental class A is in a different subset.

Table 5 Duncan test results

Class	N	$\alpha = 5\%$	
		1	2
Experimental class A	33		15.88
Experimental class B	33	14.79	
Control class	33	13.91	
Sig.		0.060	1.000

This shows that: (1) learning outcomes in the control class and experimental class B are not significantly different, and (2) experimental class A is the class that has the best learning outcomes.

Students' Learning Outcomes

There are differences in the average learning outcomes across the three classes. Figure 2 shows the average *pre-test* and *post-test* scores.

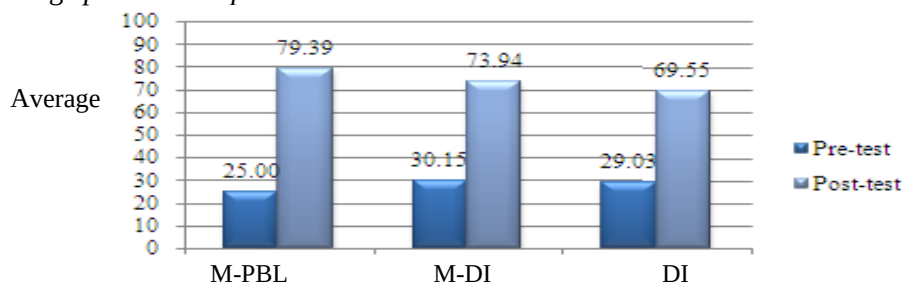


Figure 2 Value *pre-test* and *post-test*

The Minimum Learning Completeness Standard (MLCS) in chemistry is 70. Figure 3 shows the students' learning completeness.

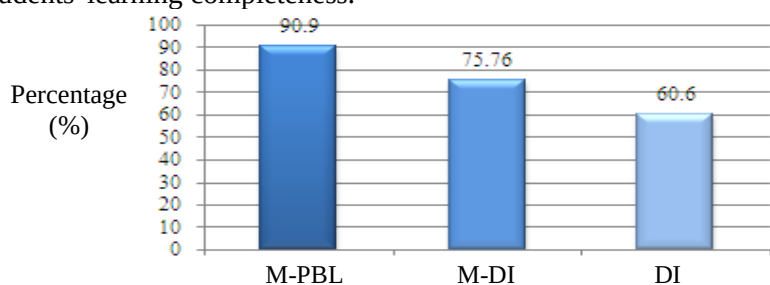


Figure 3 Percentage of completeness of learning outcomes

Based on Figure 3, the data show significant differences in learning outcomes only in the M-PBL class. The M-DI and DI classes apply direct teaching, but students are trained to use metacognitive strategies in the M-DI class. Based on its characteristics, metacognitive strategies emerge through four situations, namely when (1) justifying a conclusion or defending an objection, (2) formulating questions, (3) making correct conclusions, considerations, and decisions, and (4) experiencing difficulties in solving problems. In the DI model, students are not confronted with problems; therefore, applying metacognitive strategies in learning does not influence learning outcomes.

The application of different learning models also leads to different student activities during the learning process. The learning process of the M-PBL class begins with the emergence of a problem. In contrast, the M-DI and DI classes begin with the teacher's explanation of the material, and the percentage of student activity is shown in Table 6. Direct teaching is teacher-centered and tends to be one-way teaching that can lead to student disengagement and unoptimized learning activities. Even though it is not significant, applying metacognitive strategies in direct teaching is quite helpful for students in recalling previously studied material. The M-PBL class showed significant learning outcomes by encouraging students to discuss and learn in groups with the teacher's assistance. The primary role of the teacher in PBL is to introduce contextual problems to students. When students are tasked with problem-solving without teacher explanations, it enhances their use of metacognitive strategies.

Metacognition is the awareness of one's cognitive processes, including knowledge of what is known and what is not. In a learning context, students understand how to learn, their abilities and learning modalities, and the best learning strategies for effective learning (Avargil et al., 2018; Norman et al., 2019; White & du Boulay, 2024). The combination of metacognitive strategies within the PBL model allows students to think more and discuss with their peers while still knowing and monitoring each other's thinking. Therefore, students are aware from the beginning of their learning and the limitations of their knowledge of what they will learn, until they finally realize that they have achieved their learning goals. Metacognitive strategies help students express what is in their minds

during the learning process, enabling them to achieve learning goals and to become independent learners. This aligns with the main aim of the teaching strategy, namely assisting students to learn as independent learners, which is also one of the objectives of the PBL model (Arends, 2012).

Table 6 Percentage of student activity observation results

No.	Observed activity	Percentage of observation results		
		M-PBL Class	M-DI Class	DI Class
1.	Form groups according to instructions.	95.35	92.17	20.00
2.	Listen to the teacher's explanation of the material.	82.45	80.14	76.82
3.	Read the teaching materials given.	83.66	79.12	67.12
4.	Conduct discussions to work on LKS questions.	71.26	62.30	20.00
5.	Ask about missing material.	75.26	70.77	60.61
6.	Answer questions asked by the teacher.	65.36	61.88	66.06
7.	Work on evaluation questions.	80.95	80.59	79.09
8.	Conclude the material that has been studied.	68.23	60.53	55.61
Mean		77.82	73.44	55.66

In the PBL model, the learning process begins by presenting a problem, with the metacognitive aspect of this step being declarative knowledge. This step refers to students' knowledge about information that is already known, unknown, and needed to carry out the task. In group discussions, students first need to formulate the problem; this can be guided by the teacher's instructions to write down what they already know on a metacognitive sheet. This activity aims to connect previous material with new material, making the problem's direction clear and helping students understand their learning goals. This is in line with Bruner's theory (Mao et al., 2024), which states that the interconnection between new knowledge and previous knowledge results in a reorganization of the cognitive structure, which then creates meaning and allows individuals to understand the new information provided in depth. Ausubel also added that learning is meaningful if the information students will learn is organized according to the cognitive structure they already have; therefore, students can relate the new information to that structure (Ausubel, 2012). The initial stage of the metacognitive strategy is the conscious stage of learning, which aligns with the two theories that emphasize students' construction of thoughts, the first step in the PBL model. This contrasts with the M-DI class, which gets an explanation of the material from the teacher without first building the concept in the students' minds.

In the step of organizing students to learn, students are directly involved in the learning planning stage with metacognitive aspects. When students engage in discussion activities during group investigations, they study problems, express ideas, and collect data, which involve declarative, procedural, and conditional knowledge, as well as monitoring abilities.

Observation results show that students with high activity, when faced with problems, tend to continue carrying out activities such as reading repeatedly, working on questions by looking for examples of similar questions, expressing opinions, and asking friends and teachers. Meanwhile, students with low activity tend to wait for the results of discussions with group members and read as little as possible. However, by writing down instructions for metacognitive strategies, less motivated students can be helped to demonstrate their declarative knowledge by recalling the material they have studied and checking their understanding.

Bruner's theory emphasizes that knowing is a process, not a product, and is related to the learning phases of receiving information, transformation, and assessment. This means that learning is an active process in which students construct new ideas from their initial knowledge. Students select and process information, build hypotheses, and make decisions in their cognitive structure (Rannikmäe et al., 2020; Suyono & Hariyanto, 2011).

The percentage of student activity in the M-PBL class is higher than in the M-DI class, both of which use metacognitive strategies. The learning model in the M-PBL class, namely the PBL model, requires students to be more active. In the M-DI class, even though students also work in groups, they receive material through teacher explanations during the learning process. The group's function is only to work on practice questions after receiving an explanation of the material, using metacognitive strategies that each student still uses to think through the problems.

In the M-PBL class, groups can have different opinions as students construct their own knowledge and exchange ideas with group members, whereas in the M-DI class, each student tends to have the same thoughts or concepts, based on what the teacher has taught and what the students have absorbed. In discussion activities, declarative, procedural, and conditional knowledge, as well as monitoring skills, are important for helping students solve problems. These students' declarative knowledge already exists at the conscious learning stage, through the metacognitive strategy monitoring stage, and each student has different initial knowledge, goals, and plans when faced with problems. Students gain procedural and conditional knowledge during the monitoring stage, including task completion, purpose, and timing, as part of their learning process.

Learning in the DI class is carried out through direct teacher explanations, followed by practice questions for each student. Students' activities are limited to listening, reading, asking, answering, and working on questions without any discussion to exchange ideas. Each individual already has their own knowledge and metacognitive abilities. However, students in DI classes are not trained to express this metacognitive knowledge and ability to help them complete learning tasks, which affects lower learning outcomes.

Metacognitive strategies involve stages of conscious learning, planning, monitoring, and reflection. Students should be aware of their learning process. Figure 4 shows the percentage of students using metacognitive strategies.

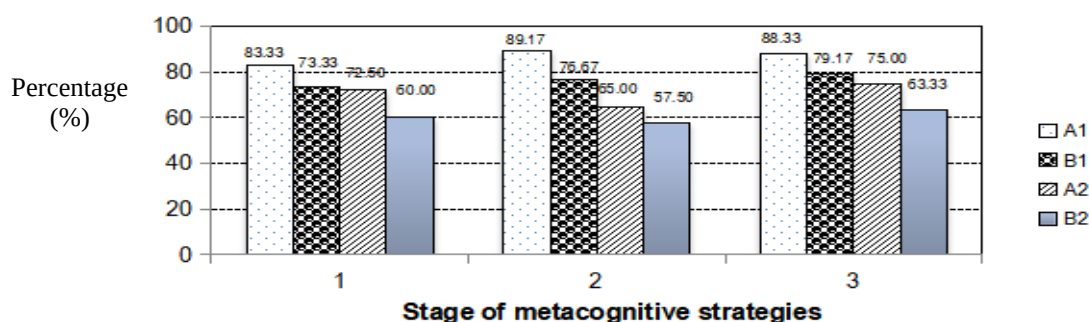


Figure 4 Percentage of students' metacognitive strategies in the experimental class

Description:

1 = Stage of the conscious learning process

2 = Stage of planning and monitoring

3 = Stage of reflection (evaluation)

A1 = Student with the highest score in the M-PBL class

B1 = Student with the highest score in the M-DI class

A2 = Student with the lowest score in the M-PBL class

B2 = Student with the lowest score in the M-DI class

Based on Figure 4, student awareness in the learning process influences learning outcomes. At this stage of the conscious learning process, students who know their learning goals, have initial knowledge, are self-motivated, and are aware of their abilities are better prepared to participate. At the learning planning stage, students who are ready to receive lessons can organize the lessons they will deliver. At each meeting, students fill in these metacognitive strategy statements to train themselves to increase awareness in their learning process. Students who know their learning goals are aware of their strengths and weaknesses, so they can decide whether to address their weaknesses or change to achieve their goals. Table 7 compares students' statements A1, B1, A2, and B2.

Table 7 Student statements in metacognitive strategies

Question	Student	Student Statement
What do you know?	A1	I have learned about stoichiometry in reactions where the substances are not equivalent, namely in the presence of a limiting reagent.
	B1	Understand chemical calculations, electrolyte solutions, and their reactions.
	A2	Calculations about stoichiometry. Today, we will learn about solution stoichiometry.
	B2	Understanding this material is challenging, and studying it can be hard.
What are you doing?	A1	First, identify the question and search various sources, resources, or examples of similar questions to solve them.
	B1	Follow the lesson by paying attention to the teacher's explanation.
	A2	Try to use, study, understand, and identify the reactions that occur and their calculations.
	B2	Try to understand by paying attention to learning.
How do it? What is the result?	A1	Keep learning so that you get good results.
	B1	Practicum was successful, and I understood it.
	A2	Do it very well so that you understand.
	B2	The results obtained are not satisfactory.

Table 7 shows that students with high levels of awareness, planning, monitoring, and self-assessment know themselves better than students whose classes are filled only with material provided by the teacher. Students with the lowest scores in the class are aware that their ability to learn the material is lacking, but they also lack a clear study plan. Some students recognize that their abilities are adequate but struggle with organizing their learning. Despite this, they achieve satisfactory results through self-reflection, motivating them to exert more effort. Metacognition is a learning tool that can be applied through various methods, notably metacognitive training, which employs questioning and strategies such as problem-solving and cognitive awareness in M-PBL models. A key strategy is self-questioning, which enables students to monitor comprehension and facilitates self-testing (Perry, Lundie, & Golder, 2019). This strategy leverages schema theory to connect new information with prior knowledge, enhances comprehension through active processing, and fosters engagement with the content. Metacognitive strategies facilitate students' development as independent learners, particularly by fostering self-awareness, initiating action, and evaluating progress. Especially in chemistry learning, self-questioning aids in linking concrete and abstract concepts, empowering students to learn and improving students' learning outcomes actively.

Analysis of teacher observations, completion of metacognitive sheets, and interviews with these four students show that each student has distinct metacognitive knowledge and abilities. A1 students have high awareness, planning, monitoring, and reflection in their learning activities. The learning activities carried out in class are in line with the statements in the metacognitive strategy. At the monitoring stage, student A1 was one of the students who did not give up easily when they encountered difficulties in working on questions, namely by repeatedly reading and looking for examples of similar questions.

B1 students who also have awareness, planning, monitoring, and reflection in their learning activities. B1 students have strategies for remembering important things, namely repeating by underlining important statements, making boxes for formulas, and making footnotes or marginal notes. This makes it easier for him to find and remember clues to use when working on questions. B1 students are those who actively try difficult questions. The learning outcomes of B1 students are lower than those of A1 students because, in classroom activities, B1 students receive pre-made concepts from the teacher, whereas A1 students build their own concepts.

A2 and B2 students get low learning outcomes. A2 students whose learning activities apply the PBL model must be able to develop their concepts so that their planning and monitoring skills are good. Even though they think their understanding is still slow and their memory is lacking, A2 students are among those willing to keep trying repeatedly and to ask their teachers or friends for the correct answer. Student A2's learning outcomes do not meet the MLCS because the learning activities

were not evaluated, or the learning progress was not debugged. Ability *debugging* is a strategy used to correct wrong actions in learning (Kallio et al., 2018; Rompayom et al., 2010). Student A2 is aware of his learning weaknesses but does not change his actions to improve his memory of a statement, formula, or example problem, for example, by using repetition, elaboration, or organizational strategies. This happens because students lack motivation. For B2 students, the lack of awareness, planning, and monitoring affects their learning outcomes, and they have difficulty understanding. B2 students tend to give up quickly on difficult questions. Apart from that, B2 students also realize that there is no special strategy they can use to correct their mistakes in learning. Students can occur due to various internal and external factors, such as a lack of motivation to learn, the classroom learning environment, and the learning model used. At the planning stage of exam preparation, these four students did the same thing; they worked on practice questions and reviewed class notes. Nonetheless, the degree of student comprehension reflected in these learning outcomes varies, as they are not immediate outcomes but the culmination of prior educational experiences. Table 8 presents the level of students' understanding of the learning material in the experimental and control classes for each indicator.

Table 8 Percentage of understanding level for each indicator

Indicator	Experimental class A		Experimental Class B		Control Class	
	Percentage	Category	Percentage	Category	Percentage	Category
1	56.06	Enough	90.90	Very good	92.40	Very good
2	77.27	Good	75.80	Good	37.90	Very less
3	91.92	Very good	82.80	Very good	81.80	Very good
4	84.09	Very good	64.40	Enough	61.40	Enough
5	71.21	Good	78.80	Good	48.50	Not enough
6	94.95	Very good	84.80	Very good	79.80	Good
7	70.45	Good	56.80	Enough	75.80	Good
Mean	77.99	Good	76.33	Good	68.23	Good

Information:

Indicator 1 = Write the Ionic Reaction Equation.

Indicator 2 = Determines the Reaction in the Electrolyte Solution.

Indicator 3 = Using Stoichiometry in Calculations for Electrolyte Solution Reactions.

Indicator 4 = Determines the concentration of acid or base from data titration and calculations.

Indicator 5 = Determining Substance Levels through Titration.

Indicator 6 = Determining the Appropriate Indicator for Acid and Base Titrations.

Indicator 7 = Creating Titration Graphs from Experimental Data.

The understanding of metacognitive-PBL class students is higher than in other classes. In the M-PBL class, students must actively think and interact with the group and class members. In line with the findings of research, Syahmani & Borneo (2017) and Shamdas et al. (2024) found that students who learned using the metacognitive-PBL model achieved better cognitive learning outcomes than those who learned using the PBL model. The student's learning process through metacognitive activities and strategies influences their learning outcomes, as evidenced by their *post-test* grades. Some research findings by Medina et al. (2017) and Sanjaya et al. (2017) show that comparing metacognitive development between novice and expert students revealed significant differences in metacognitive components between students who passed and those who failed, as evidenced by the scores of the two groups. Student experts have a higher average score than student novices. Scaffolding offers support systems from educators and peers for novice learners (Medina et al., 2017; Schraw, 2013). In the context of complex problem-solving for beginners, teachers need to deliver enhanced scaffolding and assistance throughout the process (for instance, by mandating the inclusion of units, as stoichiometric solution steps can be particularly challenging for novices to grasp (Dahsah & Coll, 2007; Westhuizen, 2015). Based on the discussion, research findings show that student learning outcomes with M-PBL strategies are higher than with M-DI and DI strategies only. The PBL model, with its high levels of engagement, has a greater influence on improving learning outcomes.

CONCLUSION

This study shows that (1) there is a significant difference in learning outcomes by ANOVA test among M-PBL, M-DI, and DI classes; (2) the best student's learning achievement is in the M-PBL group, as shown by Duncan's test at α 0.05; and (3) the learning percentages for the M-PBL group, M-DI group, and DI group were 77.82%, 73.44%, and 55.66%, respectively. The M-PBL model enhances student learning and results, making it a good school choice.

This M-PBL learning strategy takes more time than direct teaching and requires students to get used to carrying out metacognitive activities as instructed. One possible avenue for future research is to investigate whether the highly structured Stoich tutor environment facilitates learning, considering its strict application of the factor-label method may promote algorithmic problem-solving among students. Such approaches, which involve memorizing and executing specific problem-solving steps without engaging in conceptual reasoning, have been noted in previous studies (Schmidt & Jigneus, 2003). Although these strategies may assist students in successfully solving problems (as demonstrated in the current study), they might fall short in fostering an understanding of complex stoichiometry concepts, such as units (Taha et al., 2014).

Effective implementation of these strategies requires domain knowledge, including appropriate operations, symbolization, and terminology. In this regard, earlier research has focused on developing instructional support during problem-solving, or scaffolding, which offers learners additional structure and constraints, enabling them to adopt effective problem-solving strategies (Clark & Mahboobin, 2018; Yuriev et al., 2017). Consequently, there is a need for support in computerized scaffolding strategies as a vital instructional component to improve conceptual understanding and problem-solving capabilities within STEM education (Astuti et al., 2021; Belland et al., 2017).

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

The following statement should be used: Conceptualization, NA and SS; methodology and formal analysis, SS; writing—preparation of the original draft, NA and SS; reference manager, citation, language, ATK; finishing article, ATK and SS.

ACKNOWLEDGMENTS

Thank you to the Chemistry Education Study Program of Lambung Mangkurat University (ULM) and Senior High School 2 Banjarmasin for supporting the research for this publication.

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